CORRELATION BETWEEN FABRIC SPECIFICATIONS AND FABRIC HAND CHARACTERISTICS FOR WARP KNITTED FABRICS

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A thesis submitted in partial fulfilment of the requirements for the degree of Master of Philosophy

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CERTIFICATE OF ORIGINALITY

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ABSTRACT

Fabric hand is an indispensable characteristic for the selection of fabric and product development and the buying consideration to the manufacturers and consumers respectively. Fabric hand value reflects the subjective physiological and psychological perception of human by touching the materials and has direct influence on the sell market of textiles and garments. Such importance makes fabric hand as an attractive issue to many researchers and its continuity has not been ceased. This thesis is thus written for further study on fabric hand attributes, especially for warp knitted fabrics.

A sample size including 105 types of warp knitted fabrics produced by synthetic fibers (polyester, polypropylene and nylon) were selected as the research object. Traditional subjective evaluation and two objective measurements Kawabata Evaluation System for Fabric (KES-F) and PhabrOmeter system were employed to obtain the fabric hand properties related with stiffness, smoothness and softness. Correlations between physical parameters like weight per unit area and thickness and different types of mechanical parameters such as bending rigidity, extensibility, compression and surface roughness were also observed. Further attempts had been made to calculate the linear significance of fabric hand values drawn out by those measurement methods.

Statistical interpretations were used to descant the relationships of fabric parameters and hand characteristics. Specifications of warp knitted fabrics showed significance on fabric tensile, shear, bending and compression properties. Fabric thickness and weight were

also found to be correlated with the mechanical behavior and hand attributes of warp knitted sample. KES-F system and subjective assessment preformed satisfactory significance with the physical properties of warp knitted fabrics. However, PhabrOmeter system was measured to have relatively smaller significance than that of KES-F system.

PUBLICATIONS

Conference paper

K. Y. Yim and C. W. Kan, A Comparison Study of Fabric Objective Measurement (FOM) Using KES-FB and PhabrOmeter System on Warp Knitted Fabrics Handle – Smoothness, Stiffness and Softness, Proceedings of The 12nd International Conference on Textile Composites, Materials and Engineering, London, 21-22 August, 2014.

Journal paper

K. Y., Yim, C. W., Kan, J. K. C., Lam and S. P., Ng. Analysis of the Physical and Low-stress Mechanical Properties of KES System for Determining the Handle of Warp Knitted Fabrics (In Progress)

K. Y., Yim, C. W., Kan, J. K. C., Lam and S. P., Ng. Analysis of Fabric Handle by PhabrOmeter System for Warp Knitted Fabrics (In Progress)

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Starting from 1926 (Binns, 1926), fabric hand has been an attractive issue that raise the interests of many researchers. Over a thousand of papers and dissertations exploring the interpretation, terminology and methodology of hand characteristics have been published. Then what is the conception of fabric hand? It is actually a very subjective notion that can be influenced by the diversification of physiology, psychology and circumstance. And more important is that the observation of fabric hand is held by humans, whose minds can be affected by various factors such as nationality, age, gender, religion, and so on. That brings the difficulties to the measuring of the fabric hand values and the maintaining of consistent evaluation method.

Over nearly a hundred years, the study on fabric hand still contains bias and vulnerability. At the early stage of research, most articles focused on the fabric hand of wool, cotton and silk fabrics (Binns, 1926; Morrow, 1931; Wilson, 1932; Winn and Schwarz, 1940; Van, 1946). This mainstream continues to develop soft-hand cotton and wool apparels in recent years (Hashem et al., 2009; Sneddon, Lee and Soutar, 2011; McGregor and Naebe, 2013). On the other hand, the impact of fabric structures on hand attributes were also examined by researchers that mainly concerned on woven, weft-knitted and nonwoven fabrics (Park & Hwang, 1999; Bertaux, Lewandowski and Derler, 2007; Hasani and Planck, 2009; Mahar, Wang and Postle, 2013; Tohidi, Jeddi, and Nosrati, 2013).

However, the potential for the development of warp knitted fabrics has been raised in today's textile industry. In addition to its wide range of applications, fabric hand of warp knitted fabrics becomes one of the most significant characteristics in determining its fabric marketing and providing the fabric scope of performance and appearance. In most of the past studies, there is no comprehensive work on the hand feel property of warp knitted fabrics. Only a few studies inquired one or two mechanical properties of warp knitted fabrics. Owen (1970), Davies (1971), Yanagawa (1975), Gibson (1978 and 1979) and Dhingra (1979) tried to investigate fabric hand and bending and shear properties of warp knitted fabrics. Recent researchers also observed the bending behavior with constituent yarns and compression properties of warp knitted spacer fabrics (Miao and Ge, 2008; Ajeli, et al., 2009; Liu et al., 2011; Fatemeh et al, 2013). These showed the lack of detailed hand characteristics and narrow fabric types while investigating warp knitted fabrics. The possible functionalities of warp knitted fabrics were neglected by researchers and manufacturers so that there has been comparatively little study of sufficient types of warp knitted fabrics and integrated fabric hand properties.

On the basis of previous work, this study will contribute to a complete interpretation of fabric hand and solve the limitations on warp knitted fabrics. To evaluate its fabric handle, subjective test and objective evaluations for expressing and quantifying the overall hand properties of warp knitted fabrics will be examined. Measurements taken by different fabric hand evaluation systems can provide useful data for engineering warp knitted fabric. Two objective approaches i.e. KES-F system and PhabrOmeter system, and subjective evaluation will be used to ascertain the fabric hand value like stiffness, smoothness and softness for selected warp knitted fabrics. Systematic experimental and mathematical studies will be applied to characterize the warp knitted fabrics structural parameters and fabric hand properties. Attempts will be made to compare the assessment of subjective and objective hand evaluation. This study explores the hand feel of warp knitted fabric in technological aspects.

1.2 Objectives

This project aims to study the warp knitted fabrics from mechanical parameters aspects and fabric specifications to investigate fabric hand properties through objective and subjective evaluation. The objectives of the thesis are summarised as follows:

1) To study the relationship between warp knitted fabric mechanical properties and fabric hand feel
2) To investigate the influence on warp knitted fabrics with different physical specifications upon fabric hand characteristics
3) To explore the correlation between objective and subjective measurements with respect to overall fabric hand values

1.3 Methodology

To achieve the objectives above, the following research methodologies are employed:

- Review the background knowledge and recent development of warp knit technology and fabric hand aspects
- Perform experiments using fabric objective measurements (FOM) which includes

KES-F instruments and PhabrOmeter tester to obtain hand attributes

- Conduct investigation using subjective evaluation to achieve distinct characterisation techniques of fabric hand properties
- Explore the relationship between mechanical and physical parameters of warp knitted fabrics using linear calculation to find appropriate significance
- Evaluate the fabric hand values using stepwise multiple linear regression analysis of variance to deduce the main affecting mechanical blocks towards fabric hand

1.4 Scope of Thesis

The thesis comprises chapter with scope as follows:

Chapter 1 introduces the background of study, objectives, methodology and scope of the thesis.

Chapter 2 begins with an introduction to warp knitted fabrics and various handle evaluation methods. Brief background of fabric hand concept and its principle are highlighted. The applications of fabric objective and subjective measurement technologies provide reliable foundation and basis to this thesis.

Chapter 3 presents the experimental methodology used in the thesis. The detailed procedures of fabric preparation, operation of KES-F system and PhabrOmeter system, and the guidelines for obtaining subjective assessment are listed systematically.

Chapter 4 elaborates the evaluation of fabric hand for selected warp knitted fabrics by KES-F system. The relationships between mechanical properties are explored. The results of measurement data from the KES-F instruments are examined with the physical properties. Some correlations are found to show significant effect on low stress mechanical properties of fabric samples.

Chapter 5 reports the measurement of the KES-F system and PhabrOmeter system and the results obtained by the subjective hand assessment. From the viewpoints of comparative study, correlations are found between objective measurements and subjective evaluation. This work is necessary to integrate the influential factors of mechanical properties by comprehensive data set.

Chapter 6 introduces the technique of multiple stepwise regression analysis to understand the relationships between fabric hand value and the fabric mechanical properties measured from the KES-F instruments. The major fabric mechanical blocks contribute significantly to the explanation of the primary hand values and total hand value for the warp knitted fabrics. This chapter also introduces a multivariate technique of analysis for the low-stress mechanical properties for warp knitted fabrics measured on both the KES-F and PhabrOmeter instruments. The advantages of this technique are that it can analyze all the data set simultaneously and reduce the data set into a few key components.

Chapter 7 includes the significant results and findings obtained from the measurement so as to draw the final conclusion. The shortcoming and problems in the present work associated with suggestions of solution are outlined. Several future works are recommended.

CHAPTER 2

LITERATURE REVIEW

2.1 Warp Knitted Fabrics

Warp knitted fabrics are becoming more popular in today's textile industry. The great demand on sportswear and intimate wear, two indispensable types of warp knitted clothing, is increased in a rapid rate. In accordance with this trend, improving the fabric hand of warp knitted fabrics and designing its new patterns for end-use are essentially necessary and significant.

In warp knitting, fabric is formed by interlacing loops of yarn and vertically down in the direction of fabric formation. Each needle is fed by separate yarn for loop formation. Yarns are then shogged between the needles to chain loops into a fabric. Warp knitting machines were invented in 1775 and enabled bulk production of the simplest warp knitted fabrics (Wynne, 1997). In 1947, Karl Mayer established the first warp knitting machine and six years later he also introduced the first Raschel machine for paving the way for rapid-speed warp knitting technology (Ray, 2012).

In particular, the structures of warp knitted fabrics are different from those of woven and weft knitted fabrics as its physical properties are very much a function of its structures (Dewi, 1971). Warp knitted fabrics exhibit advantageous properties in that dimensional stability equal to that of woven and with elasticity comparable with that of weft knitted fabrics (Zhang et al., 2013). They are also snagging resist on the technical face side and are not as bulky as the double knits. Most of the fabric structures give nice, clean and balanced loop on surface and yarns cannot be unroved from any edge of warp knitted fabric (Yue, 1991).

2.1.1 Types of Warp Knitted Fabrics

Warp knitting is a unique machine technique as it was developed without ever having been a technique by hand. Warp knitting represents the fastest method of fabric production from yarn than weaving and weft knitting since 1990s (Kadolph, 1993). In 2013, the world's fastest warp knitting machine has been invented to producing fabrics at high speed 4400 min^{-1} (Karlymayer, 2013).

Based on the features of warp knitting, the machines are classified into two categories, namely Tricot and Raschel (Ray, 2012). Warp knits can be distinguished by the machine used to produce the fabric. There are a number of fundamental differences between Tricot and Raschel machines. Tricot machines use a single set of spring-beard or compound needles. The sinkers used in Tricot knitting machine control the fabric throughout the knitting cycle. Tricot knitting machines with computer-controlled guide bars, electronic beam control and computerized take-up are able to knit 2000 courses per minute. They are used for the production of apparel and household fabrics by continuous filament yarns. In contrast, Raschel machines use latch and compound needles and are usually coarser in gauge than Tricot machines. Fabric in Rachel knitting machine is controlled by high take-up tension and the sinkers are only used to ensure that the fabric stays down when the needle rise. Raschel machines are capable of processing staple fibre and continuous filament yarns for furnishing, industrial and jacquard fabrics (Kadolph, 2010)

2.1.1.1 Tricot Warp Knits

Tricot warp knitting machines typically employ either spring-bearded or compound needles. The majority of tricot machines operate with only two guide bar. Tricot warp knitting creates a gentle and low tension on the fabric being knitted due to the small angle of fabric take-away (Anonym, 2011). The tricot machine is the mainstay of the warp knitting industry and it is a high-speed machine in knitting width up to 260 inches for fine fabrics. By using low-cost multifilament yarn for fabric production, tricot fabrics provide strength in the straight-grain direction and expansion in the cross-grain direction. Tricot fabrics are lightweight (polyester fibre content), soft, good drape and somewhat resilient. Lockknit is used in most tricots. The longer underlaps on the technical back of the fabric improve fabric extensibility, cover and handle. Tricot knits are among the most popular fabrics used in apparel. They are important in interlinings, linings, lingerie, underwear, swimwear and athletic apparel (Baugh, 2011).

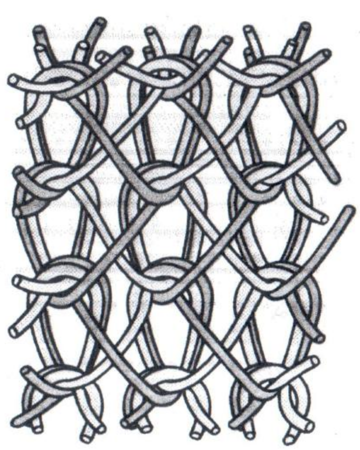

Figure 2-1 Full Tricot (Wynne, 1997)

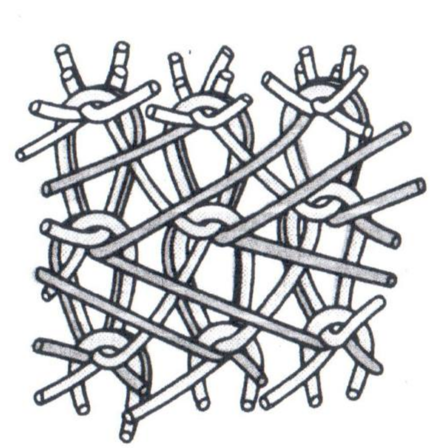

Figure 2-2 Lockknit (Wynne, 1997)

Full Tricot

Full tricot is made on the machine that uses one set of needles and two guide bars. The two underlaps balance each other exactly as they cross diagonally between each wale producing upright overlaps. Filament yarns are used in either smooth or textured form. Plain tricot is lightweight and has exceptional strength and durability, and can be heat-set for dimensional stability.

Brushed Tricot

Brushed tricots have fibers raised from the fabric surface for the purpose of creating a hairy or fuzzy third dimension, called a napped surface (Baugh, 2011). The knit stitches have long underlaps. One set of yarns is carried over three to five wales to form floats on the technical back; the second set of yarns which provide strength and durability interloops with adjacent yarns. The long floats are cut when the fabric is brushed in finishing. The brushed side is used as the fashion side, even though it is the technical back. Napping feel warm to the touch and this warm hand can be a functional result. Brushed tricot fabrics, most commonly made of synthetic fibers such as polyester and nylon, are relatively inexpensive in production cost. Brushed tricot can be used in loungewear, women's wear, shoes, slacks, upholstery and draperies.

2.1.1.2 Raschel Warp Knits

The raschel warp knitting machine has one or two needle beds with latch needles set in a vertical position with up to 78 guide bars. Its high take-up tension is suitable for open fabric structures such as laces and nets. Raschel machines are more versatile and are used for a wide variety of fancy pattern fabrics production (Bharat, 2011). Raschel knits can be used for technical products such as laundry bags, fish nets, dye nets and safety nets.

Mesh

Mesh is a fabric with mostly holes or spaces framed by tightly interloped yarns, yet have a soft and stretchable hand. The size and shape of the fabric holes and their spacing on the fabric surface can have great variety. Mesh fabrics have become an important fabric for athletic garments, women's lingerie and underwear. They are inexpensive and can create interesting texture. Mesh is often used as a jacket or pant lining for comfort and act as wicking layer for faster moisture evaporation (Baugh, 2011).

Powernet

Power mesh is a raschel knit fabric produced to create breathable comfort while providing powerful elasticity and compression. Invented to accommodate underwear that requires the garment to retain shape and stay in place on the body, power mesh provides important function for specialized undergarments and body-conforming fashion designs (Baugh, 2011). Differences in net structures are the result of different loop constructions, different sizes of openings and different types of yarns. Multifilament microfiber polyester or nylon yarns are used for the two-bar ground construction, and spandex or other elastomer is laid in by two other guide bars. Power net fabrics can be used in swimwear, dancewear and intimate apparel; they can also be used in theming, medical and automotive industries (Kadolph, 2010).

Spacer Fabric

Warp knitted spacer fabric consist of two separately produced fabric layers which are joined back to back at the time of knitting (Anand, 2003). The thickness of spacer fabric depends on the gap between the two needle beds, type of yarn and structure of the two base fabrics. The compression and resilience properties of spacer fabric depend upon the material and pattern of lapping of the guide bars (Ray, 2012). A wide variety of possibilities exist for the structure of the two fabrics, the joining yarn, and the thickness of the three-dimensional fabric. The major benefit of spacer fabric material is to create bulk, softness, flexibility, resilience properties for specific products. These fabrics are used in vehicle seat covers, interiors, seat heating systems and mud flaps.

Tricot and raschel machines account for more than 98 percent of all warp-knit goods. The remaining 2 percent contribute by simplex and Milanese machines. Simplex machine is similar to the tricot machine and uses spring-beard needles, two needle bar and two guide bars. It is used mainly in gloves. Milanese machine produces diagonal warp knitted fabrics. It uses both spring-beard and latch needles. Milanese fabrics are high quality and expensive.

2.1.2 Fabric Identification Characterization

The structure of a warp knitted fabric is dependent upon several factors. The number of guide bars used determines the number of separately controlled sets of yarns, with each guide bar feeding a set of yarn to the needles. The order of threading or sequence in which the warp threads are passed through the eyes of the guides alters the structure. If two or more guide bars are used, it is not essential to provide each guide in each bar with a warp thread. The arrangement of each needle in the knitting width receives at least one warp thread at each course.

The lateral or lapping movement of the guide bars which wraps yarn around the needles also affects the structure. These movements are controlled from either interchangeable pattern wheels or from pattern chains consisting of varying heights of links which can be built up to give the required guide bar movements. There are two basic terms used in warp knitting to describe the sideways or lapping movement of the guide bars. The overlap is a lateral movement of the guide bar on the beard or hook side of the needle, and it usually extends over one needle space only. The underlap is the lateral movement of the guide bar on the side of the needle remote from the beard or the hook, and the extent of this movement is only limited by mechanical considerations.

The type and linear density of the yarns used will also determine fabrics such as area density. Special mechanisms are available for producing held stitches, tuck stitches and figured fabrics, raised effects and full-width weft insertion, with the latter providing a means of creating fabric stability in the width direction (Wynne, 1997).

2.1.3 Wide Varieties of Applications in Textile Industry

With respect to economic and technological development, warp knitting products are getting much more attentions because of their wide varieties of applications in the industry. Mesh and tricot are two of warp knitted fabrics that have excellent performance such as light mass, smooth surface, good shape stability and breathability.

Investigation for the characteristics of warp knitted fabrics according to their structure is essential to design the fabrics for end use.

Warp knitted fabrics have great potential of applications in many areas such as apparel, engineering and composite reinforcement, and mattress and automotive. Warp knitting technology plays very important role on the fields of technical and medical textiles and their significances are ever greater. Experts claim that the annual consumption of warp knitted fabrics is increasing by 3.8% in average and it can reach about 24 million tons in 2010 (Ali, 2011).

Safety and Geotextiles

The most spectacular development of warp knitting can be registered in case of spacer fabrics. It is a newly developed substitute for polyurethance (PU) foams as cushioning materials and is three-dimensional textile structure consisting of two separate outer fabrics joined together but kept apart by spacer yarns which are generally monofilament (Liu & Hu, 2011). Spacer fabrics can substitute foam in seats or beds, in orthopaedics support devices, in bras and shoes. It can serve in smart clothes as heat insulation or for forming of ventilation passages. As a type of geotextiles spacer fabrics can be used to lead off water from the soil. In manufacturing of composites used in the motor industry or ship building they can work as reinforcement inlay. Using proper yarns or with application of special treatment they can be electrically conductive, flame retardant, antibacterial, etc. (Armankan & Roye, 2009; Abounaim et al., 2010).

Medical and Surgical Textiles

There are more applications of warp knitted fabrics in other areas, for instance, warp knitted fabrics can be used as medical textiles for upholstery fabrics for wheelchairs, shoes insoles for improved shock-absorption and moisture balance, decubitus prophylaxis by avoiding pressure points, humidity and traffic jam heat, special medical fabric 'balance snake' can aid therapeutic exercise for those with perception disturbance. Medical textiles have played an increasingly important protection role in the healthcare industry due to the long-term demand of aging consumer and healthy lifestyle proponents. Medical textiles accounted for 9% of global consumption of technical textiles in 1990 and consumption is predicted to have annual growth at 4.5% through 2010 (Sparrow, 2009).

Sport and Leisure Textiles

As a wide variation in designing warp knitted fabric is possible, high-performance athletic apparel, swimwear and casual wear can be produced to keep up with market needs. Tricot fabrics come in a variety of surface textures for different athletic applications. Warp knitted fabric uses multifilament yarns for making ideal smooth surface and polyester microfibers for allowing quick moisture evaporation to create comfortable sportswear (Baugh, 2011). According to Statista (2014), the global sportswear market from 2011 to 2014 had a total value of approximately 146 billion U.S. dollars in revenue and it is estimated to generate about 165 billion in 2017. Such enormous market share implies the growing importance of warp knitted fabrics and the concern of its sensory function.

Intimate Textiles

Intimate apparel is considered as the second skin of human. Many intimate products are made of warp knitted fabrics including bra, panties, camisole, corset, girdle and stockings. Tricot and powernet are ideally suited for lingerie and undergarment as their unique structures can contribute to superior molding and snagging performance. Fine gauge tricot delivers a new level of glamour and appeal with the look of silk and exhibiting a modern, elegant and seductive luster (Modaasia, 2014).

2.2 Characterization of Fabric Hand Property

2.2.1 Definition of Fabric Hand

The term "Fabric Hand" was introduced as early as 1930 when Peirce described it as customers' perception (Peirce, 1930). It is a comprehensive physical, psychological and social response to touching a fabric (Dargahi & Najarian, 2004; Mahar & Postle, 1983). Fabric hand has also been defined as "the subjective assessment of a textile obtained from the sense of touch. It is concerned with the subjective judgment of roughness, smoothness, harshness, pliability, thickness, etc." (Denton & Daniels, 2002). Simply, fabric hand is an individual's response to touch when fabrics are held in the hand. In standard evaluation, hand is defined as the tactile sensations or impressions which arise when fabrics are touched, squeezed, rubbed or otherwise handled (AATCC EP5 and AATCC 202).

2.2.2 Fabric Hand Descriptors

Fabric hand is a comprehensive perception formed by many aspects. Its property is among the hardest to measure, and few standard methods have been developed for determining them. Traditionally, producers, retailers and consumers have evaluated these properties subjectively and by practical experiences (Hearle et al., 1969). A number of hand descriptors have been used to describe the response of touch: smooth, rough, stiff, soft, etc. The complex interplay of these descriptors determines a person's response to the hand of a particular fabric. A fabric that does not resist bending or squeezing, but recovers easily and is lightweight, may be described by someone touching it as "soft" whereas one with some of the opposite characteristics may be termed "crisp" or "stiff". Smoothness in a fabric would be preferred over roughness for some uses (Lam & Wong, 2011).

A number of separate fabric mechanical properties contribute to the overall evaluation of hand. In AATCC evaluation procedure for subjective evaluation of hand, it lists four physical attributes as hand elements: compression, bending, shearing and surface properties (AATCC EP5). Subjective evaluation of hand involves the perception of a fabric by human raters. A particular perception is usually a combination of one or more physical sensations, for example, sight, tough, or hearing and some form of value of judgment (Brand, 1964). The judges, who may be inexperienced or expert, are asked to rate the hand of a fabric relative to other fabrics or to a standard fabric.

2.2.3 Factors Affecting Fabric Hand Value

Fabric hand is a complex parameter. It is mainly related with the fabric low stress mechanical parameters such as tensile, compression, bending, shear, surface roughness and physical parameters like weight per unit are and thickness. In textile material there are many factors, such as yarn structure, planar structure and finishing treatments, which affect the fabric hand. Properties of yarns and fabrics are influenced by the degree of twist in the yarn. Fine and filament yarns contribute to smoother surfaces and spun yarns make fabric rougher (Das et al., 2011).

Fabric hand is also influenced by foldability, compressibility, flexibility, pliability, stretchability, and surface friction. Most of the researchers proposed measuring of the above value. Others suggested measure hand related fabric mechanical parameters believed to be related to subjective ratings and preference of sensory attributes (Shishoo, 1995; Kim & Slaten, 1999).

Other than above all, fabric hand can be changed by finishes, softeners, and coatings (Chen et al., 2000; Frydrych and Matusiak, 2003; Jeguirim et al., 2010). Starches make fabrics stiffer and less flexible, whereas softeners have the opposite effect. Finishing is an extremely complex subject because of the large number of changes that occur in fabric properties during a finishing sequence. The effects of many finishing operations are interactive. By using various finishing treatments, different kind of end products can be produced from warp knitted fabrics (Pan et al., 1988).

2.2.4 Consumers' Expectation on Fabric Hand

Nowadays fabric hand feeling has become a significant factor in consumers' buying decision (Wong & Li, 2002). Fabric hand is the most important fabric parameter related to the textiles intended to judge the apparel quality. Fabric hand value influences customers inclination towards the material and usefulness of the product and it has direct impact on the selling ability of the apparel. This fabric characteristic is very much important to the fabric manufacturers, garment designers, and merchandisers on the selection of fabrics and product development (Kim & Slaten, 1999).

Quality and comfort of fabrics are served as significant attributes in the purchase process (Philippe et al., 2003; Kaplan & Okur, 2008). Some consumers weigh comfortable and well feeling and touch more important than appearance (Kazuya et al., 2004). Fabric hand properties represent a significant contribution to consumers' overall acceptance and preference (Kergoat et al., 2012).

The quality and performance of fabric has been evaluated by consumers and textile producers subjectively by means of the hand touch of fabric. Fabric characteristics affect the perceived touch and surface properties turned out to be strongly involved in subjective hand perception (Lord et al., 1998; Yoon et al., 1984). The fabric handle property of a fabric is a critical characteristic that affect consumer's preference and decision making process. For instance, some consumers show a preference for textiles characterized by a soft feel. Other consumers prefer textiles with rougher hand attributes and give more importance to the visual attributes of the textiles when forming a judgment.

In addition, consumers act differently while they use handle information as a source of pleasure or as a source of information about products (Kaiser et al., 2005). On one side, consumers get information about the quality of the product in terms of performance, strength, ease of care, etc. On the other side, touch and anticipated touch can induce positive or negative affective responses, such as pleasantness, surprise, enjoyment and irritability. A need for touch scale can measure consumer preference for haptic information in a purchase context (Peck & Childers, 2003; Kergoat et al., 2012). Consumers with a greater need to touch the products show less confidence in product judgments when they had no opportunity to touch those products. As a consequence, consumers with high demand of need for touch spent more time touching the product and softness and smoothness are appreciated more by consumers (Kamalha et al., 2013).

2.3 Instrumentation of Fabric Hand Property

2.3.1 Fabric Objective Measurement (FOM)

Fabric handle assessment is often conducted by experienced judges in textile and garment production and by consumers when making buying decisions for apparel and other textile products. Peirce (1930) first proposed the evaluation of fabric handle using a series of measurable low-stress physical and mechanical properties of fabrics. Howorth and Oliver (1958) pioneered the application of multiple factor analysis to identify the factors affecting the handle of suiting materials. According to their analysis, the handle of worsted suiting can be specified in terms of three quality attributes--- fabric smoothness, stiffness and thickness.

Later on, researchers have developed various objective measurement methods to quantitatively represent the fabric hand properties since 1980s. Textile objective measurement is concerned with characterizing textile materials in accordance with their physical and mechanical properties (Stylios, 1989). The mechanical properties of fabrics under low stress are of primary importance because they are similar to those created during manufacture and wear. This is an important consideration because ready-to-wear garments are unlikely to be subjected to heavy loads or to vigourous bending and shear moments, or to be compressed under high pressure.

The meaning of “fabric objective measurement” as defined by Bishop (1996), is “the evaluation of fabric handle, quality and related fabric-performance attributes, in terms of objectively measurable properties”. The principal aims to identify and assess quantitatively and to control the properties that contribute to the perception of fabric and garment quality in specific end-uses. A description of the fabric objective measurement concept preferred by Postle (1990) is “that a necessary and sufficient set of instrumental measurements be made on fabrics in order to specify and control the quality, tailor-ability and ultimate performance of apparel fabric”. Two instrumental systems that have been developed to determine these mechanical and physical properties are the KES-F system and the PhabrOmeter system.

2.3.1.1 Kawabata Evaluation System for Fabrics (KES-F)

The most well-known objective fabric hand measurement method is Kawabata Evaluation System for Fabrics (KES-F), invented by the Hand Evaluation and Standardization Committee (HESC) in 1980. It was developed by Dr. Sueo Kawabata and his co-worker Dr. M. Niwa to relate objective measurement of the important properties in fabric hand to subjective evaluation. This method measures numbers of fabric mechanical properties directly (Kawabata & Niwa, 1980, 1882, 1884, 1989). The subjective component of the system was supplied by a team of textile experts in Japan who evaluated a large number of apparel fabrics. Hand descriptors in terms of stiffness, smoothness, fullness and softness were developed. These separate hand properties were termed as primary hand values. The system relies on the multiple linear regression technique to correlate the mechanical measurements data to subjective fabric hand evaluation, and shows clear physical interpretation of test results.

The quantitative component of the system was determined by a series of instruments engineered by Kawabata. These instruments measure fabric responses to low deformations such as occur in handling textiles. The method of measuring fabric mechanical properties involves a complete fabric deformation-recovery cycle for tensile, shear, bending and lateral compression properties. In all cases, the deformation-recovery cycle is accompanied by a significant energy loss or hysteresis.

Fabric Mechanical and Surface Properties

The instruments of KES-F system are used to explore fabric mechanical and surface properties so as to ascertain fabric hand values. The mechanical properties such as tensile, bending, shear and surface properties are measured in fabrics wale and course directions. Three compression properties two physical properties can also be measured. A total of 17 fabric properties can be examined under standard condition.

Tensile Property

Tensile property can be measured by cramping and appling extension on fabric sample along the test direction. Rate of tensile strain is 0.004/sec and recovery process is measured until tensile force reaches 500gf/cm (Figure 2-3). As deformation is applied along length direction and the strain in width remain zero, such extension called strip biaxial deformation. Four characteristic values expressing the mechanical properties in the warp and weft directions are tensile strain, linearity, tensile energy and resilience.

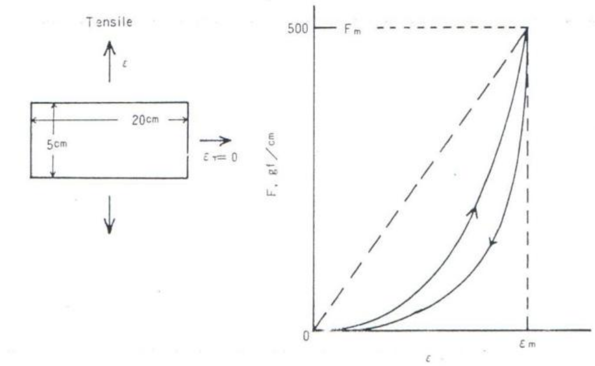

Figure 2-3 Principle used in KES F-1 instrument for fabric tensile property

Shearing Property

Shearing property can be obtained by an overlapped deformation of strip biaxial tensile and shear deformations. In Figure 2-4, constant tension 10gf/cm is applied along the direction orthogonal to the shearing force. The velocity of the shearing is taken as 0.417mm/sec and the rate of shear strain is around 0.00834/sec. Maximum shear angle attains at 8 degree and the characteristic values of shear stiffness and hysteresis are measured at shear angle 0.5 degree and 5 degree.

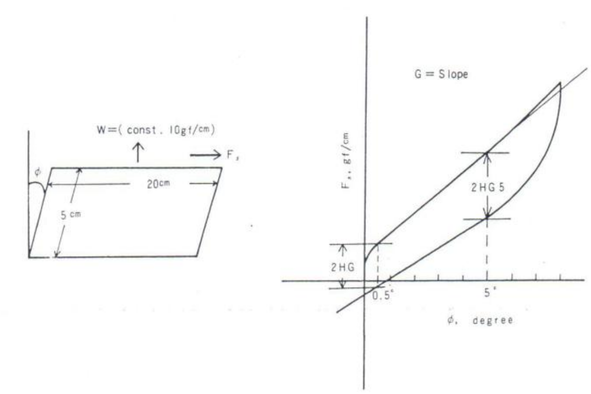

Figure 2-4 Principle used in KES F-1 instrument for fabric shear property

Bending Property

Pure Bending can be measured between the curvatures K= -2.5 to 2.5 with constant rate of 0.5(cm^{-1})/sec. Characteristic values of bending rigidity and bending moment of hysteresis are taken in the range of K= 0.5~1.5 and -0.5~-1.5 (Figure 2-5).

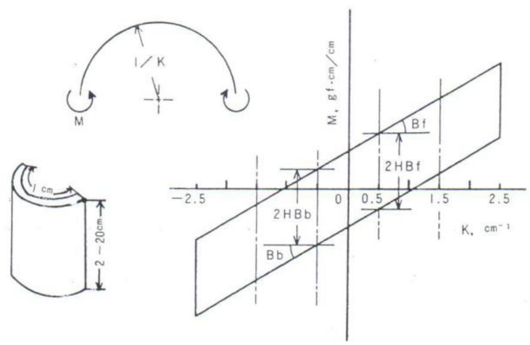

Figure 2-5 Principle used in KES F-2 instrument for fabric bending property

Compression Property

Two steel circular plates sizing $2cm^2$ are used to measured specimen compression property. The compression velocity is 20μm/sec and the recovery process is taken by the same velocity when the pressure attains at $50gf/cm^2$ (Figure 2-6). Four characteristic values are taken as linearity, compression energy, resilience and specimen thickness.

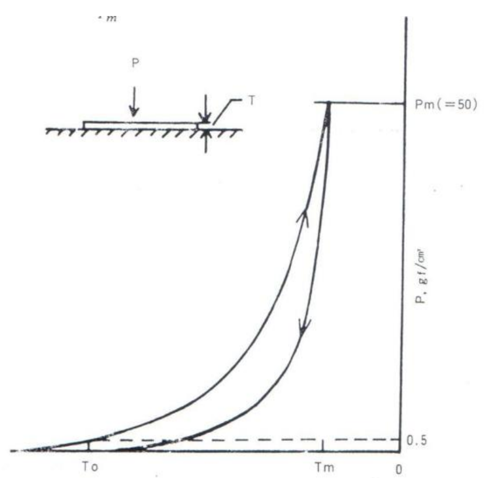

Figure 2-6 Principle used in KES F-3 instrument for fabric compression property

Surface Property

Surface friction and roughness are measured by using a steel pianowire contactor which simulates human fingerprint. A dead weight is used to apply 50gf compressional force during measurement. Specimen is tested at constant velocity 0.1cm/sec horizontally while the tension force per unit length is kept at 20gf/cm. Result analysis can be obtained from the curves of friction force versus displacement (Figure 2-7). Characteristic values of frictional and roughness measurements represent surface properties including friction coefficient (MIU), mean deviation of friction coefficient (MMD) and mean deviation of thickness (SMD).

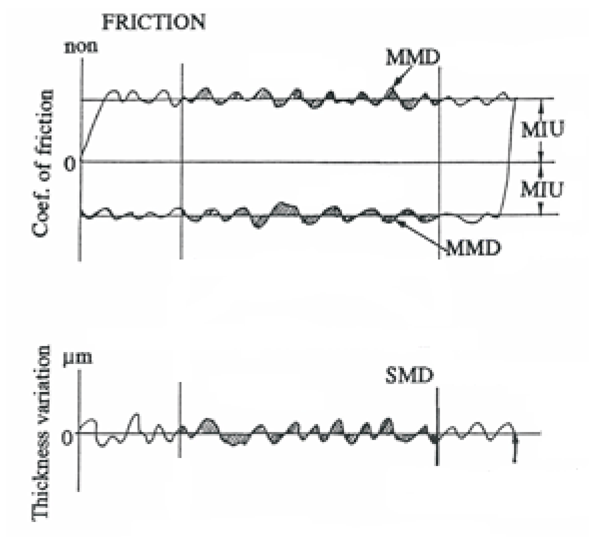

Figure 2-7 Principle used in KES F-4 instrument for fabric surface property

Although many researchers have adopted the technology of KES-F system, there are still some shortcomings. The system of analysis of data obtained from KES-F measurements uses multivariate regression to relate the fabric subjective assessments to the objectively measured fabric mechanic property data. Thus the equations for fabric hand value calculations have been formulated. Because this method of regression analysis is based on the subjective fabric hand preferences of Japanese judges, the unsuitability of the results in markets other than Japan (Behery, 1986) is inevitable, owing to the background and cultural nature of tactile sensory assessment. Another problem is that, the validity of multivariate regression analysis is often severely influenced by so called collinearity of data, which appears to exist between the mechanical parameters obtained from the KES-F instruments (Ellis and Garnsworthy, 1980). It has been pointed out that there were problems such as uncertainty, overlapping and instability in the meaning of the primary hand values (Pan et al., 1988). Limitation is also appeared on the types of fabrics used in the equations calculating fabric hand values. Those equations are mostly based on woven and weft knitted suit fabrics, which are obviously different from the warp knitted fabrics in this thesis.

2.3.1.2 PhabrOmeter System

To eliminate the influence of KES-F system's shortcoming, another objective evaluation method is employed in this project. PhabrOmeter system is a comparatively new instrument that was invented based on the following concept: ring method. In 1988, this alternative approach has been discussed to measure fabric smooth together with fabric hand properties (Pan et al, 1988). The basic concept is making the sample fabric go through a flexible light circle. Sample fabrics are pulled or pushed through a designed circle, which was believed to be a better medium for simulation of different aspects of fabric hand (Strazdiene et al., 2003). The forces when pulling or pushing the sample fabric are measured as a function of time and the curve generated is recorded.

PhabrOmeter System is then designed and established by Nu Cybertek in California, USA, based on the research by Pan and his co-workers (Pan, 2007; Pan et al., 1993). It is the latest development of fabric objective hand evaluation system. The PhabrOmeter system comes with intelligent software that analysis the complex fabric force-displacement curve directly via pattern recognition programme and multivariate data analysis. It provides the following information on fabric hands, namely (1) drape coefficient; (2) winkle recovery; (3) extraction curve and numerical features; (4) eight fabric hands attributes and their weights and (5) relative hand value (RHV). The benefits of this new system are easy and fast to operate. In 2013, AATCC developed the standard test method for the PhabrOmeter system relative hand value (AATCC 202).

PhabrOmeter system is used to quantity the human tactile sensory perception. The principle of PhabrOmeter system is insertion/extraction of a piece of circular fabric through a nozzle. Fabric deformation during extraction from the nozzle includes: compression, bending, biaxial extension and friction. For a properly designed nozzle, the fabric extraction process shows the sample is deformed under a very complex yet low stress state including tensile, shearing, bending and frictional actions, similar to the stress state when we handle a fabric. Test sample fabrics, with size of $100cm^2$ in circle shape, are pulled through a light circular metal hole. Forces are recorded as a function of time alone the whole testing process, which only takes 22 seconds to undertake one testing. Consequently, all the information related to fabric hand is reflected by the resulting load-displacement extraction curve (Enric, Xacier & Josep, 2014).

Weighted Euclidean Distance is used to measure objectively the fabric Relatively Hand Value (RHV) between the measured fabric and a designated reference fabric. This method is found to be very useful in ranking or preference for fabric handle, to verify of a new fabric product by comparing new and old fabric fingerprints. Eight handle features are calculated based on a corresponding “feature transform matrix” which has been derived from a series of extraction curves using a pattern recognition technique (Wang et al., 2008; Ishtiaque et al., 2003). These 8 parameters were believed to represent different aspects of fabric hand. Pan defined first three parameters as stiffness, smoothness, softness (Pan, 2006). With high correlation analyses result with Primary Hand Value (PHV) output from KES-FB, stiffness, smoothness, softness respectively.

The PhabrOmeter system has been configured for measurements on a broad variety of fibrous sheets, including woven and nonwoven fabrics as well as paper tissues etc (Wang, Mahar & Hall, 2012). The testing protocol has been established using four fabric divisions (super light, light, medium and heavy); each of these divisions covers a range of fabric linear density (Kacvinsky & Pan, 2006) and uses different combinations of mass loading on the fabric and orifice size.

2.3.2 Fabric Subjective Measurement

Evaluation of fabric quality has traditionally been assessed subjectively in both the textile and clothing industries (Vaughn & Kim, 1975). The simplest and most widely used method of subjectively assessing fabric quality is through the notion of fabric handle. The subjective judgment of fabric hand is based on human sensitivity and experience. It is true that this subjective method is the most direct method for evaluating fabric mechanical comfort, as the human body and sensitivity feel the comfort of clothing (Izabela & Lieva, 2012).

The sensory evaluation of tactile properties of fabrics has been studied for years and has given insight into the process of haptic perception of materials (Hollins & Risner, 2000; Philippe et al., 2004; Bergmann & Kappers, 2006; Jeguirim et al. 2010). Perceived touch is a multidimensional concept, but the perception of softness appeared as the most dominant aspect of texture perception of fabrics (Sülar & Okur, 2007).

Subjective assessment is one of the traditional procedures of describing fabric handle based on the experience and variable sensitivity of human beings (Martisiute & Gutauakas, 2001). Subjective feeling of fabrics is the result of a complex interaction between physiological and psychological human responses and fabric physical properties (Liao et al., 2011). AATCC has developed a standard protocol for hand evaluation (AATCC EP5). The procedure details recommendations for preparing specimens, specific methods for handling of specimens by raters, and practices for expressing evaluation results. It is recommended that specimens be visually blocked from the raters so that color and visible texture do not influence the evaluation. Descriptors such as stiff, smooth and soft will be listed as the attribute of fabric hand. Scale and rating method are used for expressing the evaluation results.

The essential steps involved in the subjective hand evaluation with particular reference to subsequent use may be defined as:

(i) the judges – in particular their expertise, education background and experience;

(ii) the criteria of descriptors – the appropriate choice for fabric attributes;

(iii) the evaluation conditions – fabric seen or unseen, controlled temperature and relative humidity; and

(iv) the method of ranking or scaling the assessments – grade and rate standards, establish reference specimen.

2.3.2.1 Judges

To determine the panel size and judges' background, addition literature review is used for better interpretation. In work on the evaluation of softness, Niwa and Ishida (1978) found no significant difference between subjective hand evaluations made by expert and non-expert judges. In addition, the services of expert judges are not widely available for research and development activities and workers in these fields are usually obliged to use panels composed of students, laboratory assistants or other consumer groups. Such panels are, on the evidence of the literature (Fritz 1990, Elder 1984, Binns 1934), capable of making consistent judgements of textile attributes and whereas their variability may be somewhat greater than that of expert panels (Stearn et al. 1984, Winakor et al. 1980). David and Ding (2005) also mentioned that subjective hand assessments are made on the basis of need or on the end use of the fabric in real life. Choosing judges that have basic background and knowledge of textiles for better understanding of ranking terminologies and definitions are essential. The issue of using larger panel sizes has been discussed by Winakor, Kim and Wolins (1980), who noted that "simple statistical measurements, such as Student's t and the correlation coefficient r, stabilize at sample size of around 25-30 persons, so this establishes a minimum panel size".

2.3.2.2 Criteria

The subjective evaluation of fabrics requires a set of criteria against which judgements can be made. Judgements that are based an individual's liking or preference, or on notions of "best" or "worst", are not appropriate in Fabric Objective Measurement (FOM) systems because preference cannot be correlated with objectively measurable fabric physical properties (Valakiene & Strazdiene, 2006).

The vocabulary associated with fabric sensory properties is very large, as can be appreciated from Brand's work (Brand, 1964) on the measurement of fabric aesthetics and Vaughn and Kim's (1975) review of the definition and assessment of fabric hand. The latter, includes a list of over a hundred fabric descriptors selected from the literature. However, when panels of expert or non-expert judges evaluate fabrics in the context of a specified end-use, they use relatively few fabric attributes as judgement criteria.

Howorth and Oliver (1958, 1964) used a panel of 25 laboratory assistants with no special experience in handling fabrics, to rank 27 samples of worsted suiting fabrics. The ranking was carried out by using a pair-comparison technique, and each judge was asked to state the reason for accepting or rejecting a particular fabric. It was found that 86% of all decisions were made on the basis of the nine most frequently used descriptors, including smoothness, softness, firmness, coarseness, thickness, weight, warmth, harshness and stiffness.

David et al. (1986) discussed the choice of descriptors with each judge and obtained words of opposite meaning so that lists of "bipolar descriptors", for example rough-smooth, were generated. The total list of words from all judges was collated and clustered (Hui et al., 2004; Lui et al., 2006). An attempt was made to associate groups of words with the published "Standard Definitions of Terms Relating to Textiles".

It is also believed that fabric hand is closely related to the physical properties of the fabric. A scientific scheme based on the computer pattern recognition technique confirmed the feel correlates with about 110 factors, and related to the highest degree where in the stiffness (37%), softness (36%), smoothness (14%) (Grineviciute, 2005). The total weight of the three factors exceed 80% of the total hand information, thus these three factors can be broadly described the state of the fabric feel.

2.3.2.3 Conditions Used for Fabric Hand Evaluation

The term "hand", defined by standard protocol of AATCC EP5 Guidelines for the Subjective Evaluation of Fabric as "the tactile sensations or impressions which arise when fabrics are touched, squeezed, rubbed or otherwise handled", is somewhat vague to allow its evaluation in either seen or unseen conditions. The systematic evaluation of handle, based on a definition that is specific to the sense of touch, might be expected to involve taking precautions to exclude bias caused by fabric appearance and possibly even by fabric odour and also any rustling sound made by some fabrics.

Elder et al. (1984) investigated the correlation between subjective finger-pressure assessments of fabric softness and objective measurements of fabric compression. A pillory box with two hand-holes was used so that the judge could not see the fabric being handled. The same group of workers used similar methods in further studies when comparing subjective estimations of fabric stiffness with objective measurements of flexural rigidity and bending hysteresis, but unseen assessments have been made by placing a screen between judges and samples.

2.3.2.4 Ranking and Scaling Fabric Attributes

In some studies, the judges have been required to evaluate fabric samples only as a “self-contained” set, either pair comparison of all possible pairs or by simply arranging the set of samples in rank order (Winakor et al. 1980, Vohs et al.1986, Chen et al. 1992). Such studies produce results in terms of the rank order of perceived suitability for particular end-uses or rank orders in terms of selected fabric attributes. However, these rank orders are not suitable as the basis for KES-F and PhabrOmeter systems that seek to predict subjectively perceived fabric attributes from objective measurements (Sular & Okur, 2008; Zeng, Ruan & Koehl, 2008). Therefore, subjective assessments of fabric properties that are intended for correlation with objective measurements are scaled in that way.

2.4 Summary

In this chapter, the literature information related to warp knitted fabrics and hand characteristic are explored. Different types of warp knitted fabrics are found to enable wide applications in textile industry. Fabric hand is defined based on various standards and influencing factors are studied. Evaluation methods of fabric hand including KES-F system, PhabrOmeter system and subjective assessment are also elaborated.

CHAPTER 3

EXPERIMENTAL DETAILS

3.1 Research Experimental Procedure

3.1.1 Collection of Samples

Fabric provider (Tai Tung International Group) is one of the major manufacturer and supplier of full range apparel and interlining for the garment industry in Hong Kong. Over 100 difference types of fabrics are designed for different purposes: from clothing to furniture to filter and more. Samples which have been widely used in sportswear, lingerie and leisure articles are selected. Mesh is the major material for lining of sports jackets, outer fabric of sport T-shirts, furniture quilting and even wedding gowns. Tricot and brushed tricot fabrics are also suited for sportswear and shoes. Large sample size of different warp knitted fabrics can represent the majority fabric production for different end uses in apparel market.

3.1.2 Preparation of Samples

Fabric samples used in this study were 105 types of warp knitted fabrics provided by Burltexplus Knitting Industrial Ltd and Tai Tung Interlining Ltd in Hong Kong. Batch samples of different fabrics without any finishing agents were collected from the company by separate deliveries. Fabrics were labeled and cut into pieces with the approximately dimensions of 20cm x 20cm for KES-F measurement and 100cm^2 for PhabrOmeter evaluation. All fabric samples were conditioned at 65±2% relative humidity and 21±2℃ for at least 24 hours before measurement. All specimens were kept individually in a BHT-free plastic bag in order to prevent getting dirty, folded and wrinkle before assessment.

3.1.3 Fabric Weight and Thickness

105 warp knitted fabrics are in different types: mesh, 3D mesh, space mesh, shiny mesh, brushed mesh, tricot, brushed tricot, micro brushed tricot, etc. The specifications of these fabrics are given in Appendix 1.

As these fabrics consist of different structures, fabric weight and thickness are distinct and need to be measured before the fabric objective measurement. Fabric weights in different size (20x20cm and $100cm^2$) and fabric thickness were calculated according to ASTM Standard D3776 and ASTM D1777 respectively. The fabric weight ranges from $55g/m^2$ to $260g/m^2$ and thickness ranges from 0.25mm to 2.26mm. These two basic physical properties are important for determining fabric hand value and fabric mechanical properties.

3.2 Experimental Details of KES-F System

In this thesis, KES-F test was conducted following instruments' manuals. Five specimens of face side for each sample were tested. The KES-F system for measurement of fabric mechanical and surface properties comprises four separate instruments, namely KES-F-1 for tensile and shear testing; KES-F-2 for bending; KES-F-3 for compression and KES-F-4 for surface testing, as shown in Table 3-1. The parameters describing the fabric mechanical and surface properties are shown in Table 3-2.

Table 3-1 KES-F system for fabric objective measurement

Machine Block	***Use***	***Characteristic values measured***
KES-F-1	Tensile and Shearing testing	LT, WT, RT, G, 2HG, 2HG5
KES-F-2	Bending testing	B, 2HB
KES-F-3	Compression testing	LC, WC, RC, T
KES-F-4	Surface testing	MIU, MMD, SMD

Table 3-2 KES-F system parameters of fabric mechanical and surface properties

Blocked Properties	***Symbols***	***Characteristic Value***	***Unit***
Tensile	EMT	Extensibility, Strain	%
	LT	Linearity of Load	-
	WT	Tensile Energy	gf.cm/cm^2
	RT	Tensile Resilience	%
Shearing	G	Shear Stiffness	gf/cm.degree
	2HG	Hysteresis at Φ=0.5º	gf/cm
	2HG5	Hysteresis at Φ=5º	gf/cm
Bending	B	Bending Rigidity	gf.cm^2/cm
	2HB	Hysteresis per unit length	gf.cm^2/cm
Compression	LC	Linearity of Compression	-
	WC	Compression Energy	gf.cm/cm^2
	RC	Compression Resilience	%
Surface	MIU	Coefficient of Friction	-
	MMD	Mean Deviation of MIU	-
	SMD	Surface Roughness	micron
Weight	W	Weight per unit area	mg/cm^2
Thickness	T	Thickness at pressure 0.5 gf/cm^2	mm

3.2.1 Operation Procedures of KES-F instruments

KES-F system is consisted of four machine-blocks such as Table 3.1. Each machine is designed to measure different mechanical properties by various testing steps as follows:

<u>KES-FB1</u>

This apparatus is used to measure tensile and shearing properties. On the hand of tensile, specimen is cramped by two chucks while one of them is mounted on the sliding base and stretches the specimen by the sliding base movement to backward direction. Tensile force is detected by measuring the torque of the drum and tensile strain by the displacement of the sliding base. On the other hand of shearing, the chuck on the sliding base moves in the direction parallel to the axis of the drum and applies the shearing deformation on the specimen. The shearing force is detected by a transducer attached at the end of the moving chuck.

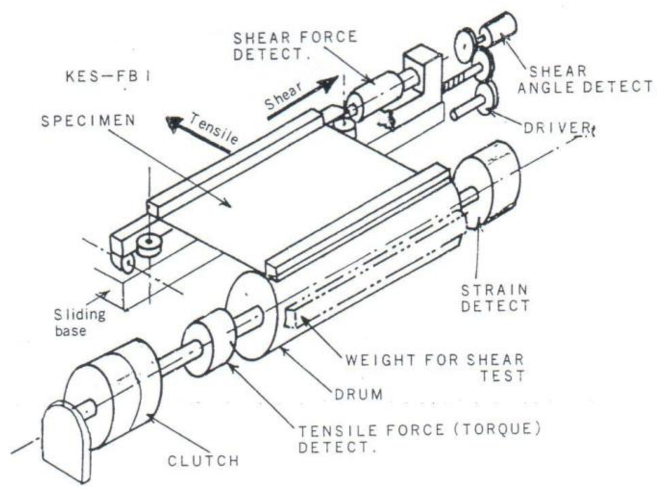

Figure 3-1 Principle of KES-FB1 tensile and shearing tester (Kawabata, 1980)

KES-FB2

For bending test, specimen is bent when one of the ends is fixed on a rod. The rod is supported by thin pianowires at its both ends. The torque induced by the bending deformation is picked up by a linear transformer as a very small amount of rotation angle of the rod.

KES-FB3

To measure compression property, specimen is compressed by two circular plates. Thickness value is taken by the thick detector. This principle is the simplest among the four KES-F apparatus.

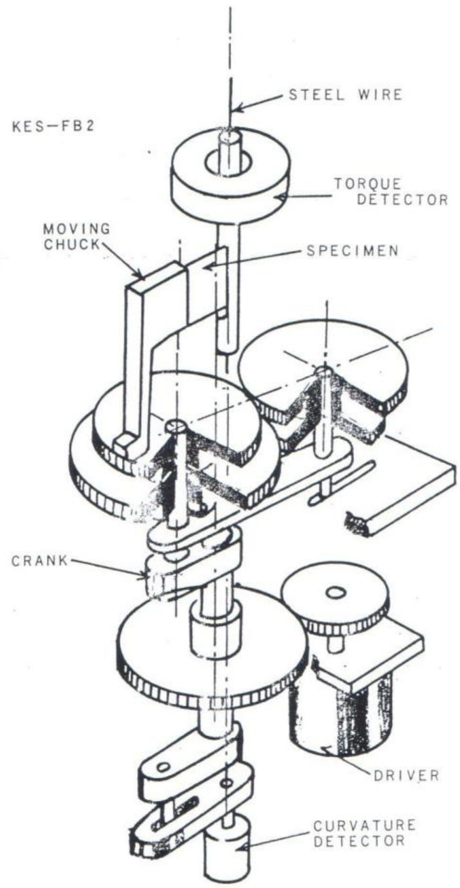

Figure 3-2 Principle of KES-FB2 bending testing (Kawabata, 1980)

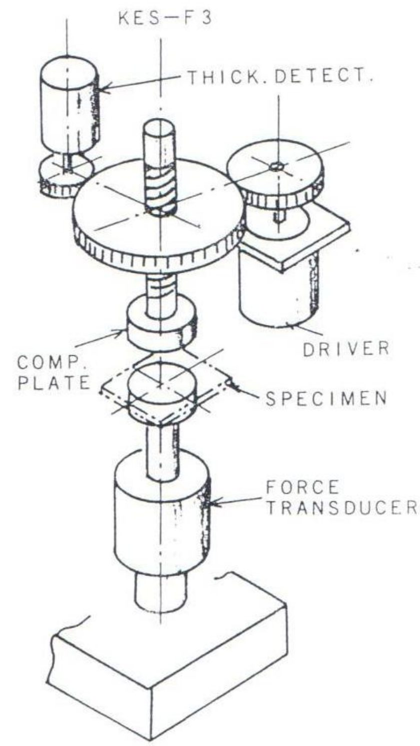

Figure 3-3 Principle of KES-FB3 compression testing (Kawabata, 1980)

<u>KES-FB4</u>

This apparatus is used to measure the surface roughness and surface friction. Specimen is moved from left to right by a rotating drum on which one end of specimen is fixed and then from right to left after that. The other end is cramped by a swing lever to give tension on the specimen. The detector of the roughness touches on the specimen and the displacement of the detector is transduced to the electric signal by a linear-transformer. The signal from the transducer is passed the filter having prescribed frequency response and integrated to compute geometrical roughness.

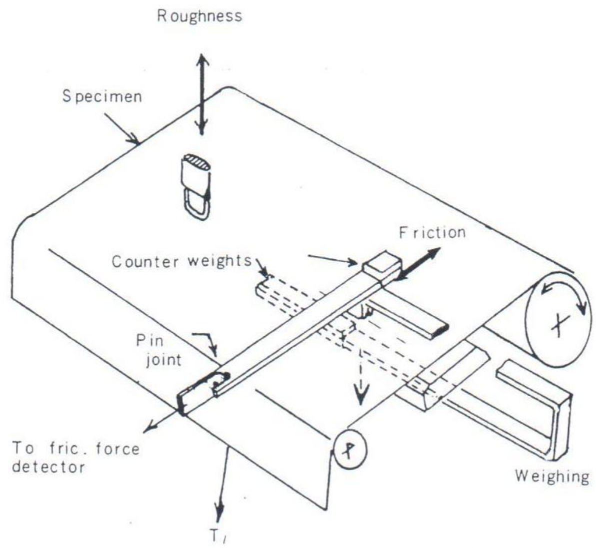

Figure 3-4 Principle of KES-FB4 surface testing (Kawabata, 1980)

The objective determination of hand is indicated as tensile, shear, bending, compression and surface properties as above descriptions. Measurements were used to predict the primary hand values (PHV), such as smoothness, crispness, fullness and softness. The total hand value (THV) was also determined from the primary hand and Woman's medium thick suiting (stiffness, smoothness, softness and soft feeling) (Table 3-3) was selected for the expression results of all fabric samples.

There are several reasons for choosing woman's suiting (KN-201-MDY) as the equation standard of fabric hand value from KES-F system.

1) Warp knitted fabrics are different from woven and weft knitted fabrics. But Dr. Kawabata and his co-workers established H.E.S.C hand expression standards based on woven and weft knitted fabrics. Therefore, calculation of warp knitted fabric hand value need more attempts for trial and error on every available equation.

2) According to the fabric types of project samples, knit and intimate and summer wear are three fundamental elements that suit for fabric description. Knit underwear in summer (KN-402-KT) and Men's summer suit were found to be too much negative results on hand values. And satisfactory results were obtained from Women's summer suit (KN-201-MDY) for better interpretation in the part of result and analysis.

3) Women's suiting can also be chosen from thin or medium thick fabric type. This classification is based on the sample thickness apparently. Project fabric samples consist of 89% and 56% within the range of medium-thick fabrics on thickness (0.323~2.490mm) and weight (9.38~42.97mg/cm^2) respectively.

4) In the primary hand expression for women's medium-thick fabrics, the term of "sofutosa" is a unique semi-hand primary hand value that expresses mixed feeling of the other three primary hands showed in Table 3-3. This hand expression is claimed to be used very frequently in market and industries because of its importance as an intensive expression. Thus this extra hand value can help to obtain more hand information that distinguishes better fabric hand.

Table 3-3 Primary hand expression and their definition from KES-F system

Primary Hand	***Definition***
Stiffness (Koshi)	A feeling related to bending stiffness. Fabric springy properties promote this feeling. A fabric that has compact weaving density and woven from springy and elastic yarn makes this feeling strong.
Smoothness (Numeri)	A mixed feeling arising from smooth, limber and soft sensations. The fabric woven from cashmere fibre gives this feeling strongly.
Softness (Fukurami)	A feeling arising from bulky, rich and well formed sensations. Springy properties in compression and thickness accompanied with warm feeling are closely related with this feeling.
Soft Feeling (Sofutosa)	Soft feeling, a mixed feeling of bulky, flexible and smooth feelings.

3.2.2 Results of Hand Value

The hand values express the intensity of the fabric hand feeling and these values are based on the standards established by the Hand Evaluation and Standardization Committee (H.E.S.C.). Chart showed in Figure 3-5 is used for examining the characters of fabric by plotting its hand value. Scale is normalized by using the mean and the standard deviation of the mechanical properties (tensile, shearing, bending, compression and surface properties) for translation formula into hand values.

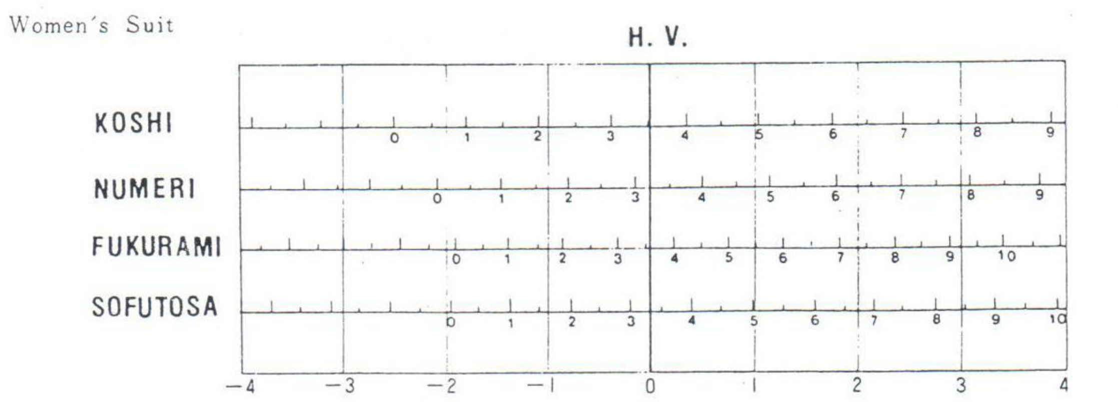

Figure 3-5 Chart for the hand values of women's medium-thick fabrics (Kawabata, 1980)

To understand the expression for good or poor hand, KES-F system helps to calculate the numerical results of primary hand value (HV) and total hand value (THV) of fabric samples. The evaluation expressions are showed in Table 3-4 and Table 3-5 as below.

Table 3-4 Primary hand value

Primary HV	***Expression***
10	Excellent
|	|
5	Average
|	|
0	Poor

Table 3-5 Total hand value

THV	*Expression*
5	Excellent
4	Good
3	Average
2	Below average
1	Poor
0	Out of use

3.3 Experimental Details of PhabrOmeter System

In this study, PhabrOmeter System is used to quantify the sensory perception in contact with human skin. Three 100cm^2 circular samples of each warp knitted fabric were cut and prepared for testing. Fabric weight and thickness were used as the information to identify the linear density for grouping. Additional weight of test plates was added according to the fabric linear density, as shown in Table 3-6.

Table 3-6 Addition test plates used for PhabrOmeter system

Fabric Type	*Linear Density Range*	*No. of Test Plates used*
Super Light Fabric (S)	< 280 μg/cm	0 additional test plate
Light Fabric (L)	280 ~ 1200 μg/cm	1 additional test plate (~2 lb)
Medium Fabric (M)	1200 ~ 3440 μg/cm	1 additional test plate (~4 lb)
Heavy Fabric (H)	> 3440 μg/cm	1 additional test plate (~6 lb)

Figure 3-6 PhabrOmeter machine for fabric hand evaluation (Wang et al., 2013)

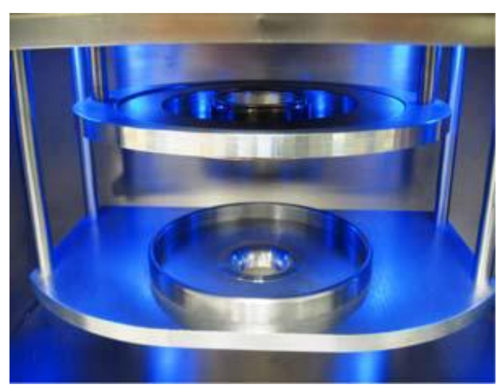

Figure 3-7 PhabrOmeter system test plate (Wang et al., 2013)

PhabrOmeter machine and test plates are showed in Figure 3-6 and Figure 3-7. Samples were inserted/ extracted through a specially designed nozzle. Fabric deformation during extraction from the nozzle includes: compression, bending, biaxial extension and friction. Fabric samples were deformed under a very complex yet low stress state, similar to the stress state when handling a fabric. A load-displacement fabric extraction curve (Figure 3-8) was obtained for each specimen and an average of three curves was used to calculate the peak and slope. All the information (Table 3-7) for the fabric hand, including eight fabric hands attributes (termed as stiffness, smoothness, softness and the other five unspecified in the system), drape, relative hand value (RHV), wrinkle recovery rate, extraction curve and repeatability were contained after measuring the extraction curve.

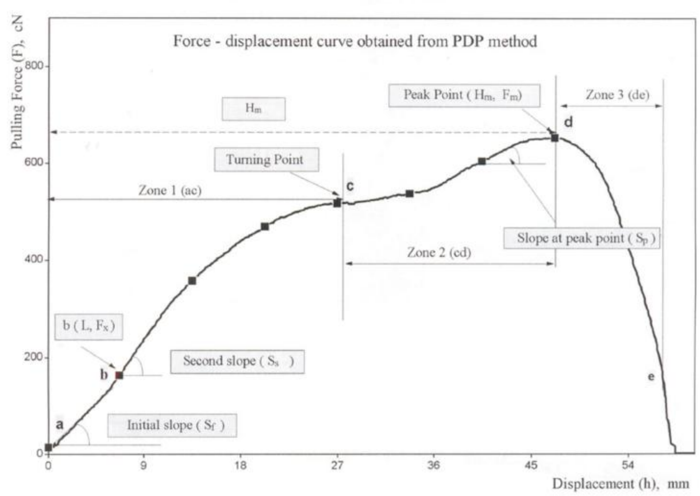

Figure 3-8 Force-displacement curve obtained by PhabrOmeter system (Hasani and Planck, 2009)

Table 3-7 Quantified data from the PhabrOmeter system

Fabric Hand Attributes	***Description***
Stiffness	Any material that is easily bent may be described as flexible, limp, or pliable; stiff and rigid are the antonyms.
Smoothness	Surface friction is a surface's resistance to slipping. Surface it can be thought of as how hard you have to push your

	fingertip to move it across a fabric.
Softness	Compressibility may be judged by squeezing a crumpled piece of fabric in your hand.
Drape Index	The extraction test is in fact a forced drape so it should be able to describe the fabric dynamic drape behavior.
Relative Hand Value	Against a reference fabric, an overall fabric performance ranking of a set of fabric samples tested.

3.4 Experimental Details of Subjective Measurement

From a technical point of view, the ultimate objective of fabric hand evaluation is to replace the subjective assessment of various quality aspects of a fabric by laboratory tests in which the personal element can be almost eliminated. Despite the complexity of this project, it is necessary that objective evaluation method should improve the assessment of fabrics by touch.

For the present study, the panel size of judges was set to 25 and was used to conduct the subjective assessment on all 105 warp knitted fabrics so that meaningful statistical measurements can be conducted. The judges for the present study hold positions in industry with working experience (expert), academic institutions with different education level from degree, master and doctor students (normal) and consumers with no related textile background (naïve). Their background information was list in Appendix 4.

The subjective evaluation of fabrics requires a set of criteria against which judgements can be made. Judgements based on fabric sensory properties are more appropriate because such properties can be correlated with objectively measurable fabric physical properties. With particular reference to subsequent use of the results in objective measurement, i.e. KES-F system and PhabrOmeter system, four descriptors were chosen in this evaluation – softness, stiffness, smoothness and total hand value. The definition of descriptors is shown as Table 3-8.

Table 3-8 Definition of descriptors used in subjective evaluation

Descriptors	***Definition***
Stiffness	Any material that is easily bent may be described as flexible, limp, or pliable; stiff and rigid are the antonyms.
Smoothness	Surface friction is a surface's resistance to slipping. Surface it can be thought of as how hard you have to push your fingertip to move it across a fabric.
Softness	Compressibility may be judged by squeezing a crumpled piece of fabric in your hand.
Total Hand Value	An overall value on fabric performance of handle.

During assessment, the view of specimens was blocked by placing samples in a black box for evaluation. Raters were requested to put their hands into the box to touch and feel the specimens. For the present work, subjective assessment of the warp knitted fabrics were evaluated on the standards of KES-F primary hand values of stiffness, smoothness, softness and total hand value. The rating scheme for these values is shown in Table 3-9.

Table 3-9 Evaluation ratings and ranking information for raters

Stiffness, Smoothness and Softness				
1	….	5	….	10
The weakest	….	weak	….	The strongest

Total Hand Value					
0	1	2	3	4	5
Fail	Poor	Fair	Average	Good	Excellent

In order to acquire the measurement results with less diversity, raters are asked to follow designated handling gesture (Figure 3-9, 3-10 and 3-11) towards the warp knitted fabric samples.

Figure 3-9 Handling gesture for stiffness:
pick up the sample, rub and press the sample with thumb and finger

Figure 3-10 Handling gesture for smoothness:
use fingertip to touch the sample with little pressure, hold down the fabric with one hand, stroke with another

Figure 3-11 Handling gesture for softness:
squeeze the sample with thumb, finger and palm to make a fist

3.5 Statistical Analysis

To execute research data analysis, statistical methods by using Statistical Product and Service Solutions (SPSS) 17 for Windows were carried out in this thesis. Collected data were analyzed through SPSS tools (Pallant, 2007) to examine descriptive variables, correlation matrix and multiple linear regression between fabric mechanical and physical properties.

3.5.1 Preliminary Analyses

Techniques of descriptive statistics were used to conduct preliminary analyses of research data obtained from fabric objective and subjective hand evaluation. Variables were analyzed by checking their mean, standard deviation, ranges and frequencies. Histograms were used to display the distribution of variables such as tensile properties. Box-plots were also used to explore the pattern and distribution of data and to check underlying outliers that possibly affected the accuracy of collected data.

3.5.2 Correlation Matrix

Scatter-plots were used in Chapter 4 and 5 to explore the relationship between two continuous variables of fabric mechanical and physical properties. Indications of linear or curvilinear were showed in scatter-plot figures and linear relationships were suitable for correlation analyses. Scatter-plots also provided correlation pattern of whether the variables were positively or negatively related. Exporting scatter-plots can also give useful information such as y equations and the values of R^2.

Simple correlation analyses were used to describe the linear relationship between two variables by generating scatter-plots. Pearson correlation coefficients were reported to explore the relationship among mechanical and physical variables of warp knitted fabrics and were presented in tables to show neat statistical significances. Various independent variables were used to obtain correlation coefficient:

1. Tensile properties: tensile extensibility, linearity, energy and resilience
2. Shearing properties: shear stiffness and hysteresis in shear angle $0.5^{\circ}/5^{\circ}$
3. Bending properties: bending rigidity and hysteresis
4. Compression properties: compression linearity, energy and resilience
5. Surface properties: coefficient of friction, mean deviation and surface roughness
6. Physical properties: fabric thickness and weight per unit area
7. Hand attributes: stiffness, smoothness and softness

3.5.3 Multiple Linear Regression Model

Multiple regression was used to explore the relationship between one continuous dependent variable and a number of independent variables (Lheritier et al., 2006). It was based on correlation matrix and allowed more sophisticated exploration of the interrelationship among a set of variables. Such analysis helped to find how much variance in a dependent variable they were able to explain as a group or block in KES-F system data (Sztandera, 2008). The independent variables used in multiple linear regression model were no. 1-5 and the dependent variables were no. 7 listed in the previous paragraph. The coefficient of determination R and R^2 value in the model summary tables in Chapter 6 indicated how well they can explain the overall models' variations, often expressed in terms of percentage. Generally speaking, when it is over 90% ($R^2 > 90\%$), it is a good model for explaining variations.

3.6 Summary

This chapter summarized the procedures of fabric preparation and evaluations. Details of testing methods including KES-F system, PhabrOmeter and subjective assessment for measuring fabric hand values were reported. Instruments and measured parameters were also presented for the implement of data collection. Various statistical analyses were introduced to show correlation and modeling methods. Observed data and variables used for result analyses helped to explain relationships between different mechanical and physical properties of warp knitted fabric samples.

CHAPTER 4

RESULTS AND DISCUSSIONS ON FABRICS PHYSICAL AND MECHANICAL PROPERTIES

4.1 Correlations between Mechanical Properties

The results of objective assessments of hand value were compared with physical properties including weight and thickness. The correlation between mechanical properties and fabric parameters were explored in order to determine whether the hand feel characteristic is highlighted under quality evaluation.

In this part, objective measurement of warp knitted fabrics using the KES-F instruments is derived from fabric low-stress mechanical parameters in terms of tensile, shear, bending, compression and surface properties.

4.1.1 Tensile Property

The extensibility (EMT), tensile linearity (LT) and the tensile energy (WT) of warp knitted fabrics shows differences in the wale and course directions. As shown in Figure 4-1, the average wale extensibility is 7.57% and average course extensibility is 4.25% for all fabrics tested. The average of LT in wale and course direction is 0.68 and 0.63 respectively. It is true that in warp knitted fabric structures, wale direction always has a higher extensibility than course direction. And the tensile energy of wale and course direction is 1.52 and 0.75 respectively. General speaking, larger tensile strain requires more power to perform sample deformation. In terms of higher extensibility of wale direction, more energy is eventually needed to extend the wale of the samples than the course direction. Such directional energy differences are the result of fabric formations in the knit structure (Choi & Ashdown, 2000). Elongation is stated to be generally greater in the wale direction than in the course direction.

The tensile resilience (RT), however, is higher in course direction than that in wale direction. The average course resilience is 56.44% and the wale is 49.28%. The tensile resilience measures the fabric recovery process in the force-extension curve. Therefore, a higher tensile extensibility contributes lower tensile resilience since the fabric recovery process takes a longer time. In particular of higher strain in course side of warp knit fabrics, the resilience result is again attributable to such compact structure of fabric samples.

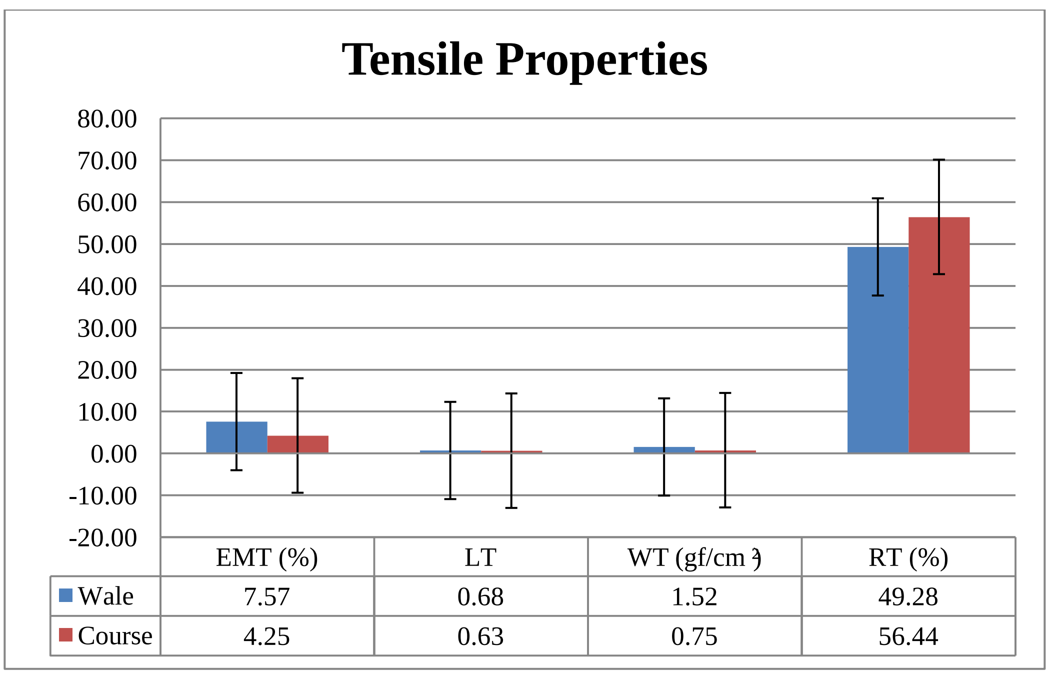

Figure 4-1 Tensile property of warp knitted fabrics

Table 4-1 Correlation coefficients for tensile parameters in wale and course directions

	EMT(w)	EMT(c)	LT(w)	LT(c)	WT(w)	WT(c)	RT(w)	RT(c)
EMT(w)	1							
EMT(c)	**0.731	1						
LT(w)	0.072	-0.037	1					
LT(c)	0.083	0.021	**0.696	1				
WT(w)	**0.845	**0.532	-0.102	-0.08	1			
WT(c)	**0.787	**0.857	-0.062	0.007	**0.815	1		
RT(w)	-0.153	0.113	*0.211	-0.016	**-0.255	-0.026	1	
RT(c)	0.079	-0.068	0.011	-0.1	0.102	0.001	**0.490	1

Where, (w); wale direction (c); course direction
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

The correlation coefficients for the tensile parameters are shown in Table 4-1. The tensile energy (WT) is highly correlated with the tensile extension (EMT) for these 105 warp knitted fabrics. Figure 4-2 and 4-3 reveal that the correlation coefficient in the wale direction between WT(w) and EMT(w) is 0.845 and in the course direction between WT(c) and EMT(c) is 0.857. Both values are significant at the 0.01 level. These results of high positive relationships indicate that tensile force is directly affected by tensile strain of the fabric sample.

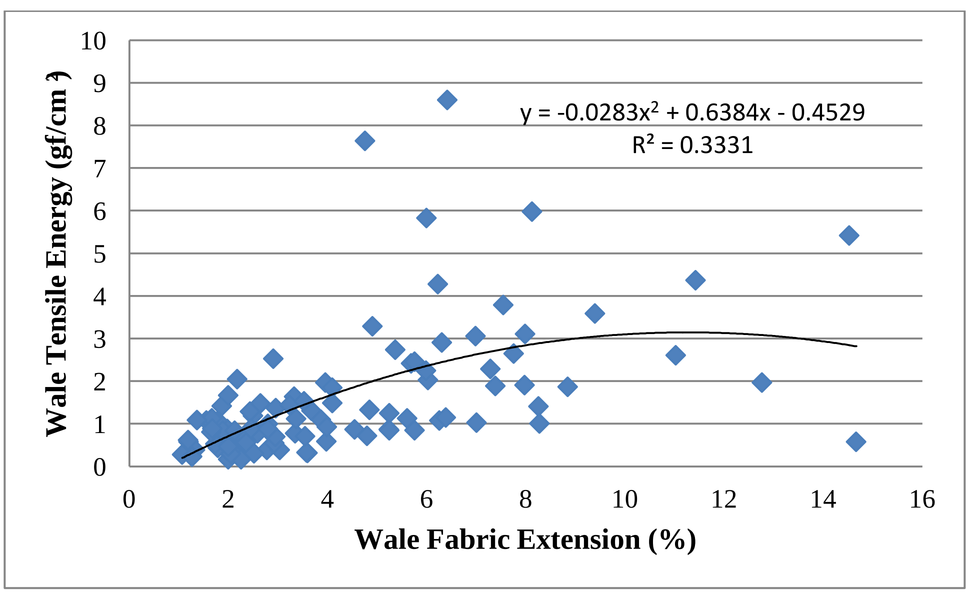

Figure 4-2 Correlation between fabric extension and tensile energy in the wale direction

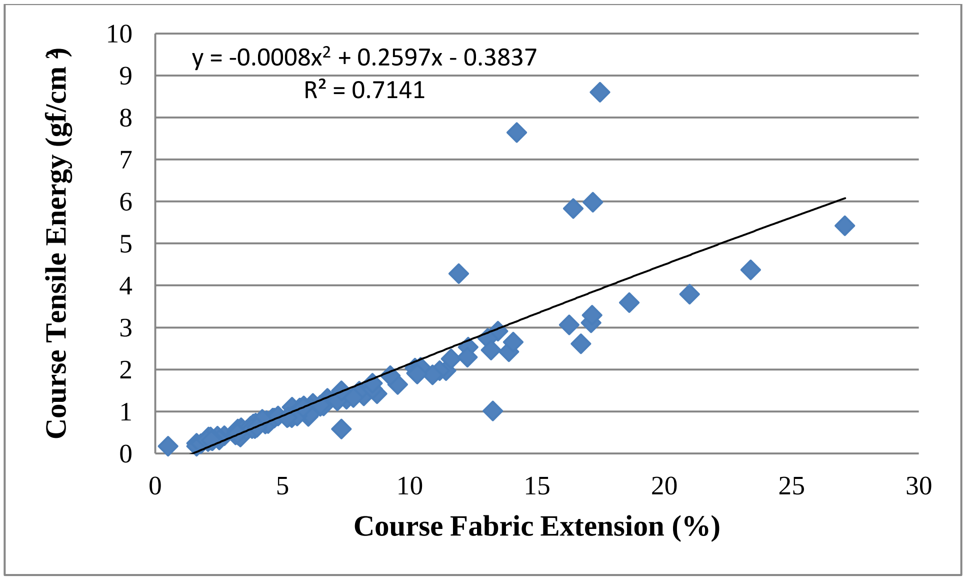

Figure 4-3 Correlation between fabric extension and tensile energy in the course direction

4.1.2 Shearing Property

Fabric shear rigidity is a measure of the displacement toward the fabric stability. Measurement of shear rigidity can be done with tension applied to the fabric in either the wale direction or the course direction. Fabric shear rigidity measures the relative movement between the wale and course. The correlation between fabric shear parameters to the wale and course directions is shown in Table 4-2. The results show that there is direct relationship between fabric shear and shear hysteresis. The correlation coefficient between G and 2HG is 0.673 (Figure 4-4) and between 2HG and 2HG5 is 0.498, both with significant at 0.01 level. However, there is a lower correlation between G and 2HG5 for which the correlation coefficient is 0.505. This means that shear rigidity is related to shear hysteresis measured at 0.5 degree shear angle on the KES-F instrument, but is less related to shear hysteresis measured at 5 degree shear angle. The results explain that the shear displacement generated larger stiffness when sample is shearing between 0 to 0.5° and less rigidness between 0.5° and 5° shear angle.

It can also be seen from Table 4-2 that the correlation coefficient between G(w) and G(c) is 0.908 thus yielding a very strong positive relationship. It should also be noted that a strong correlation was found between 2HG5(w) and 2HG5(c) being 0.807. This implies measurement of shear rigidity can be done with tension applied to the fabric in either the wale direction or the course direction.

Table 4-2 Correlation coefficients for shear parameters in warp and weft directions

	G(w)	G(c)	2HG(w)	2HG(c)	2HG5(w)	2HG5(c)
G(w)	1					
G(c)	**0.908	1				
2HG(w)	**0.673	**0.700	1			
2HG(c)	**0.663	**0.777	**0.883	1		
2HG5(w)	**0.505	**0.448	**0.498	**0.517	1	
2HG5(c)	**0.518	**0.63	**0.525	**0.693	**0.807	1

Where, (w); wale direction (c); course direction
** Correlation is significant at the 0.01 level (2-tailed).

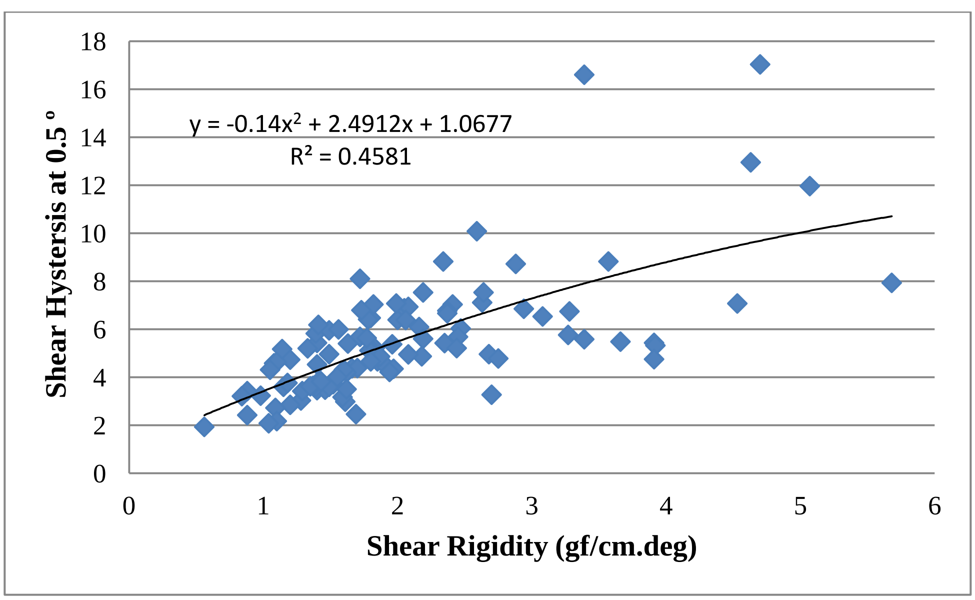

Figure 4-4 Relationship between shear rigidity and shear histersis at 0.5 °

4.1.3 Bending Property

A reasonably wide range of fabric bending rigidity is found for the 105 warp knitted fabrics. The average values of fabric bending rigidity in wale and course directions are 4.8μN.m²/m and 5.3μN.m²/m, respectively. As shown in Figure 4-5, the highest value of wale bending rigidity is 144.8μN.m²/m, and the lowest is 3μN.m²/m. For the course direction of the fabric, the highest and the lowest course bending rigidity is 147μN.m²/m and 2μN.m²/m respectively.

For all warp knitted fabrics, the bending rigidity in course direction is higher than the wale according to Figure 4-5. The unusually high value of bending rigidity (145.9μN.m²/m) for fabric no. 33 can be explained by the fact that this fabric is the thickest fabric (2.26 mm) among the 105 fabrics.

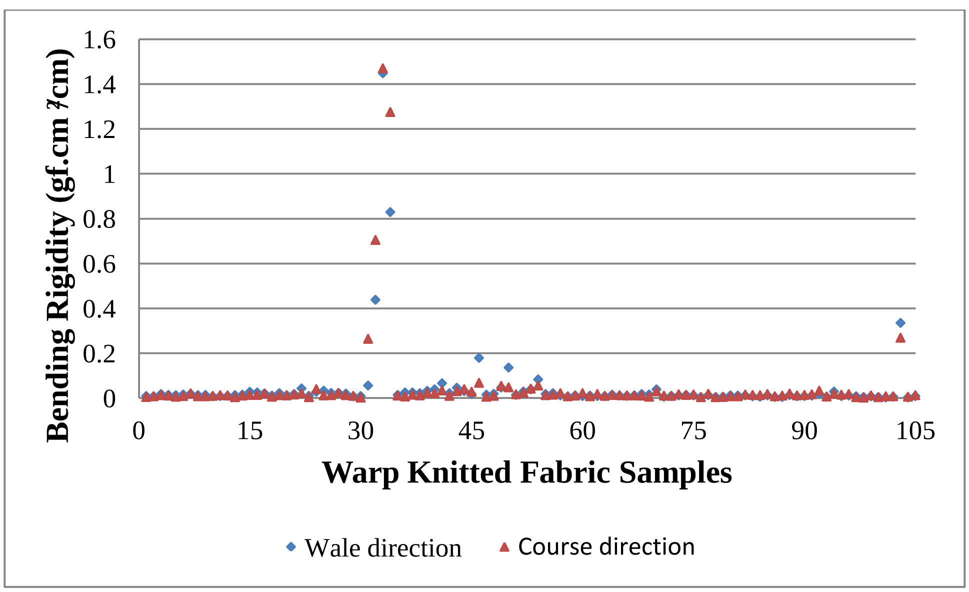

Figure 4-5 Wale and course bending rigidities for 105 warp knitted fabrics

Table 4-3 Correlation coefficients for bending parameters in wale and course directions

	B(w)	B(c)	2HB(w)	2HB(c)
B(w)	1			
B(c)	**0.966	1		
2HB(w)	**0.960	**0.908	1	
2HB(c)	**0.979	**0.990	**0.934	1

Where, (w); wale direction (c); course direction
** Correlation is significant at the 0.01 level (2-tailed).

According to Table 4-3, the bending hysteresis shows a strong relationship with bending rigidity for all warp knitted fabrics. The correlation coefficient between B(w) and 2HB(w) in wale direction is 0.96. The correlation coefficient between B(c) and 2HB(c) in course direction is 0.979. Figure 4-6 and 4-7 show the regression equation for the wale bending rigidity and the wale bending hysteresis; and the regression equation for the course bending rigidity to course bending hysteresis respectively. Both of these regression equations show high correlation coefficients. These results mean that high fabric bending rigidity generally corresponds to high bending hysteresis or inelastic energy loss during fabric bending.

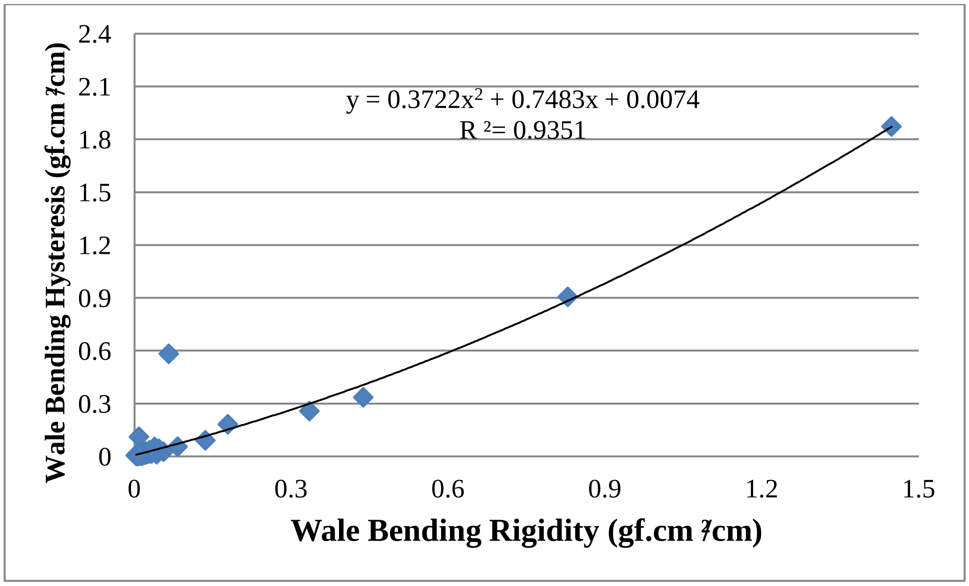

Figure 4-6 Relationship between wale bending rigidity and bending hysteresis

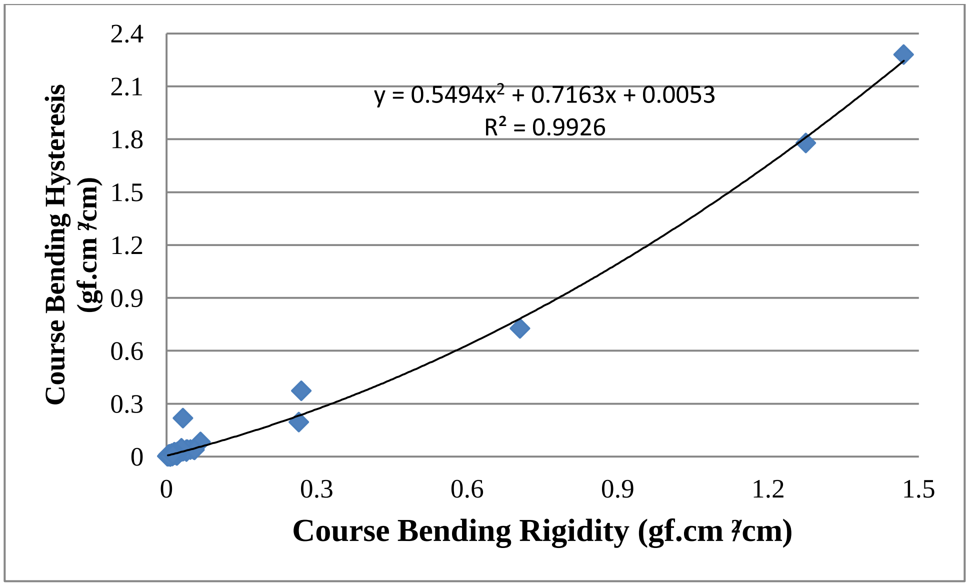

Figure 4-7 Relationship between course bending rigidity and bending hysteresis

4.1.4 Compression Property

Table 4-4 Correlation coefficients for compression parameters

	LC	WC	RC
LC	1		
WC	**0.292	1	
RC	**0.420	**0.487	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

The compression correlation results are showed in Table 4-4. The correlation coefficient between the fabric compression linearity (LC) and the fabric compression energy (WC) is 0.292 with significant at 0.01 level. The two parameters are directly related because compression energy is measured as the total energy stored and the compression linearity is measured as the ratio of compression energy stored in the fabric to the total energy or area under a hypothetical linear compression-thickness curve. As a result, a higher value of compression linearity would generally give a higher value of compression energy.

4.1.5 Surface Property

Table 4-5 Correlation coefficients of surface parameters in wale and course directions

	MIU(w)	MIU(c)	MMD(w)	MMD(c)	SMD(w)	SMD(c)
MIU(w)	1					
MIU(c)	-0.099	1				
MMD(w)	**0.353	**-0.542	1			
MMD(c)	-0.029	-0.091	**0.327	1		
SMD(w)	**0.277	-0.125	*0.212	-0.119	1	
SMD(c)	**-0.326	**0.437	**-0.578	-0.142	0.05	1

Where, (w); wale direction (c); course direction
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Fabric surface properties can be described using KES-FB-4 surface tester to measure fabric parameters such as coefficient of friction (MIU), fabric mean deviation (MMD) and fabric roughness (SMD). There is a relationship between the coefficient of friction and surface roughness. Table 4-5 shows that the two properties have positive correlation coefficients on wale and course direction which R=0.277 and 0.437 respectively with significant at 0.01 level. It indicates that the fabric friction increases at the same time raise the surface roughness.

4.2 Effect of Fabric Hand Feel by Fabric Thickness

With the result of primary hand value and total hand value, fabrics were analyzed in relation to their fabric thickness and weight respectively. Results find that these two physical properties showed different extend of effects on fabric mechanical properties of warp knitted fabric samples which were generated by KES-F system.

4.2.1 Tensile Property

Table 4-6 Correlation coefficients between fabric thickness and tensile parameters

	EMT(w)	EMT(c)	LT(w)	LT(c)	WT(w)	WT(c)	RT(w)	RT(c)
Thickness	-0.189	-0.057	-0.132	0.006	*-0.197	-0.113	0.057	*-0.202
Sig.	0.053	0.564	0.179	0.951	0.044	0.252	0.562	0.039
N	105	105	105	105	105	105	105	105

Where, (w); wale direction (c); course direction
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Observed from Table 4-6, there is no significant relationship between fabric thickness and tensile properties. This result reveals no surprise because of the high elasticity feature of those 105 warp knitted fabrics. KES-F tensile instrument was designed for woven and weft knitted fabrics with low extensibility on both fabric directions. Before conducting tensile measurement, special setting was used to coordinate the high extension of warp knitted fabrics, especially for mesh and powernet samples. In Appendix 2, the ranges of EMT, LT, WT and RT values are large. And Figure 4-8 shows that several outliers exist on both wale and course tensile variables. These extreme outliers affect the statistical inspection of variability. The outlying cases occurred since some warp knitted fabric structures exhibit high elasticity.

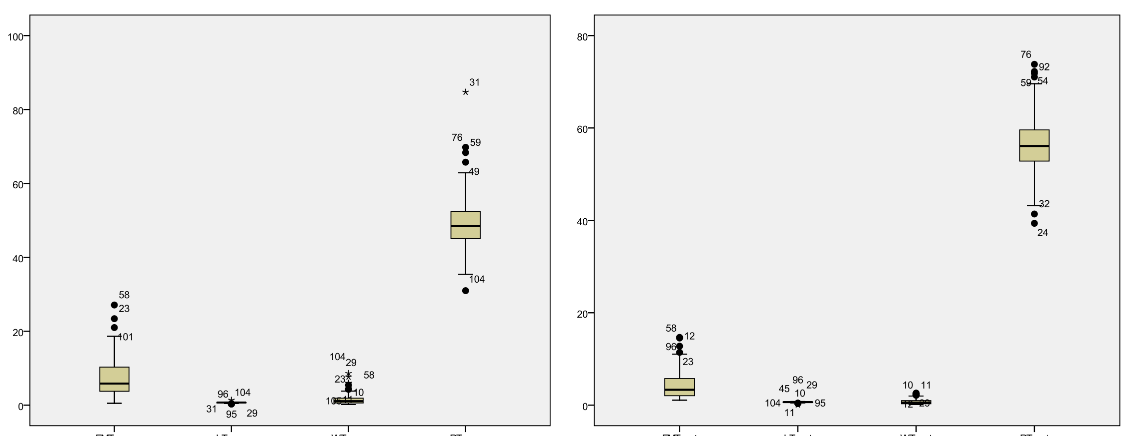

Figure 4-8 Box-plots showing outliers of tensile values in wale and course directions

4.2.2 Shearing Property

Table 4-7 Correlation coefficients between fabric thickness and shear parameters

	G(w)	G(c)	2HG(w)	2HG(c)	2HG5(w)	2HG5(c)
Thickness	**0.500	**0.470	**0.309	**0.399	**0.602	**0.645
Sig.	0.000	0.000	0.001	0.000	0.000	0.000
N	105	105	105	105	105	105

Where, (w); wale direction (c); course direction
** Correlation is significant at the 0.01 level (2-tailed).

In Table 4-7, shear rigidity and shear hysteresis show positive correlation with fabric thickness, which the correlation coefficients between G, 2HG, 2HG5 and thickness are all significant at 0.01 level. The results reveal that the thicker and bulkier is the fabric, the more difficult it is to shear paralleled in wale and course yarns. Figure 4-9 shows medium strength of the relationship between fabric thickness and shear stiffness. Moreover, the correlation coefficient between thickness and shear hysteresis measured at 5 degree shear angle is higher than that measured at 0.5 degree shear angle. This result is caused by the larger elasticity generated in continuous shearing between 0.5° to 5° with larger value of thickness.

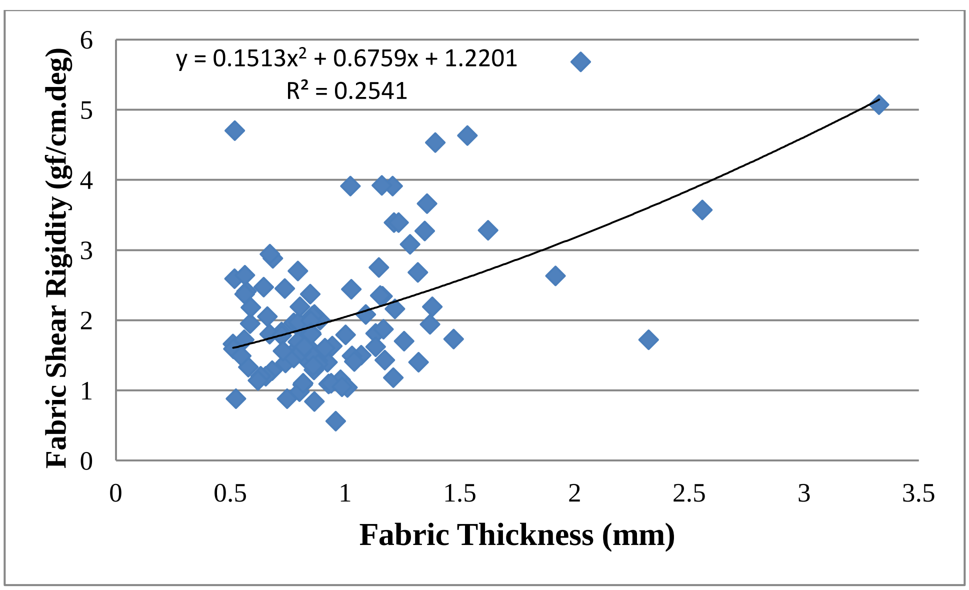

Figure 4-9 Relationship between fabric thickness and shear rigidity

4.2.3 Bending Property

Table 4-8 Correlation coefficients between fabric thickness and bending parameters

	B(w)	B(c)	2HB(w)	2HB(c)
Thickness	**0.772	**0.735	**0.742	**0.733
Sig.	0.000	0.000	0.000	0.000
N	105	105	105	105

Where, (w); wale direction (c); course direction
** Correlation is significant at the 0.01 level (2-tailed).

As shown in Table 4-8, there is a strong correlation coefficient between fabric thickness and bending properties where correlation coefficient is R=0.772 and 0.735 respectively at 0.01 significant level. The relationship between these two properties in wale and course direction is very high as R^2=0.9471 and 0.8209 which is respectively shown in Figure 4-10 and 4-11. This physical property affects the bending rigidity value with large extend because the thicker is the fabric, the harder it is to bend the fabric.

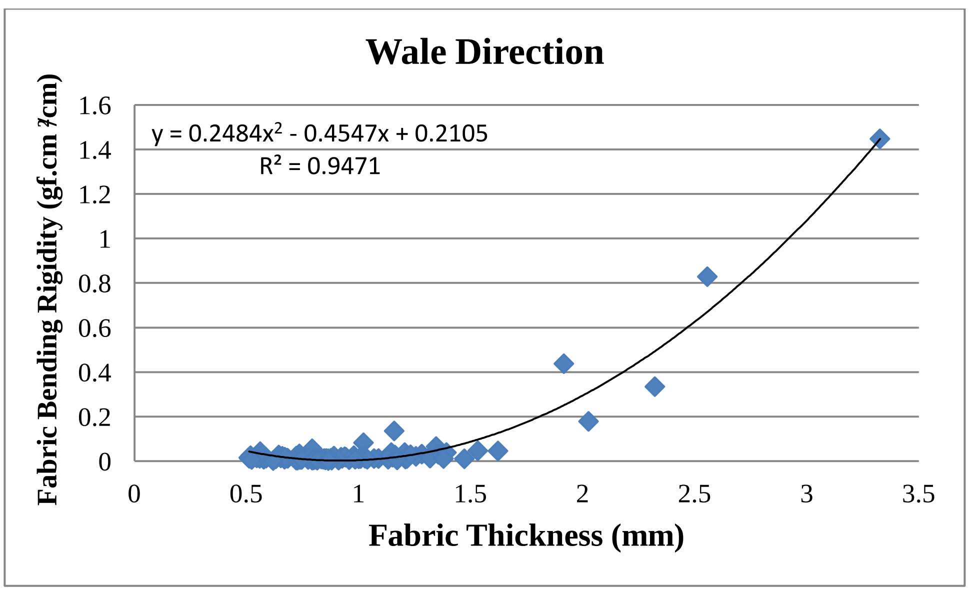

Figure 4-10 Relationship between fabric thickness and wale bending rigidity

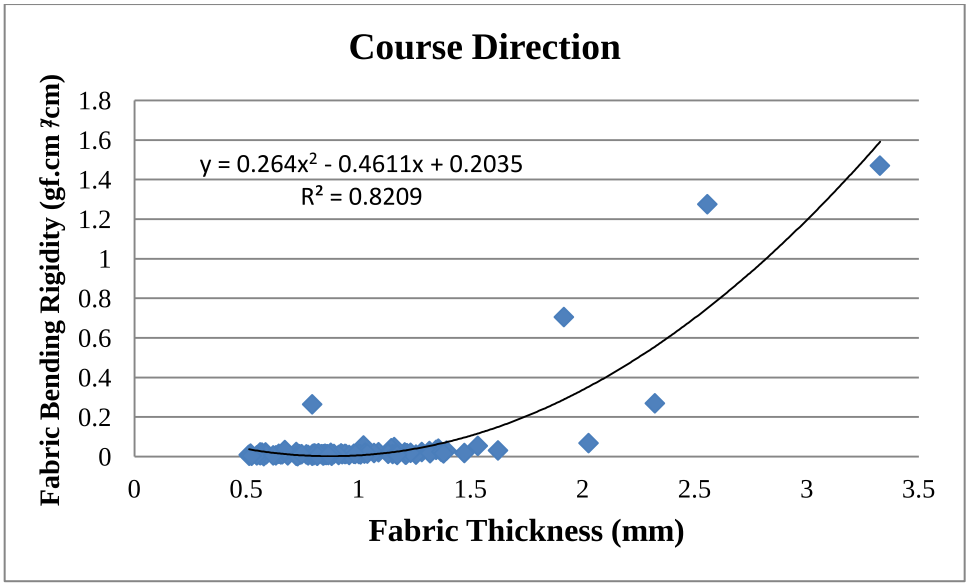

Figure 4-11 Relationship between fabric thickness and course bending rigidity

4.2.4 Compression Property

Table 4-9 Correlation coefficients between fabric thickness and compression parameters

	LC	WC	RC
Thickness	**0.553	**0.795	**0.642
Sig.	0.000	0.000	0.000
N	105	105	105

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

The compression energy (WC) shows the strongest significant correlation with fabric thickness (T). The correlation coefficient between WC and T is 0.795. The relationship which R^2=0.7428 is violent between these two properties as shown in Figure 4-12. This result illustrates that a thicker fabric need larger compression energy.

Based on Table 4-9, a strong relationship exists between the fabric thickness (T) and fabric compression resilience (RC) as shown in Figure 4-13. The correlation coefficient between RC and T is 0.642. That implies the fabric compression resilience raises for increasing fabric thickness. This result suggests that light fabric is relatively difficult to compress, having high compression resilience, or, in other words, thicker fabrics are more elastic in compression than thin fabrics.

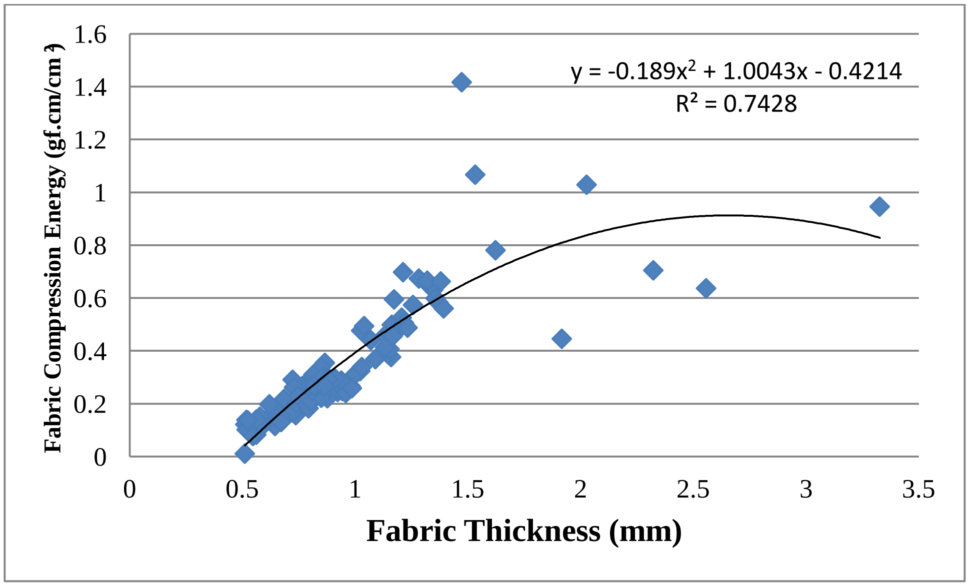

Figure 4-12 Relationship between fabric thickness and compression energy

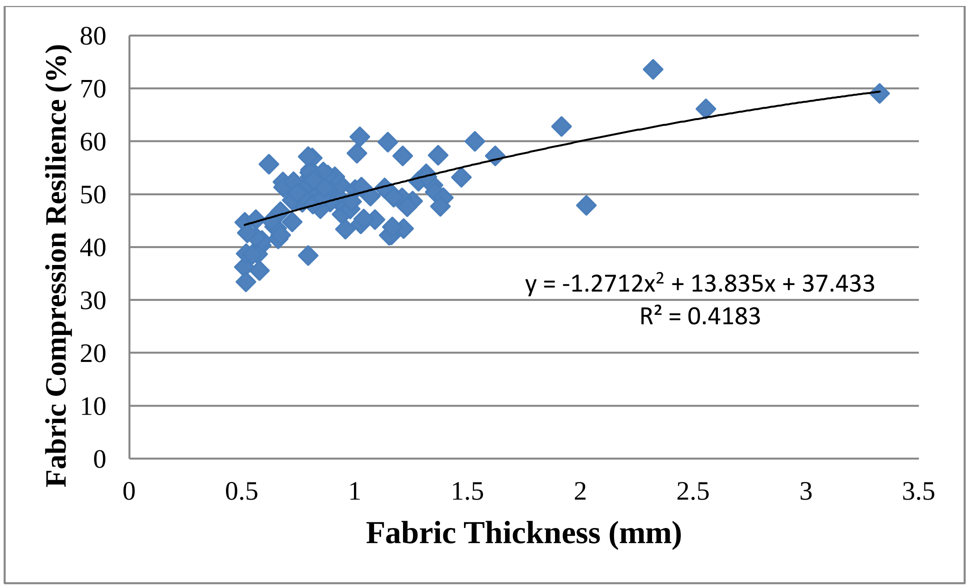

Figure 4-13 Relationship between fabric thickness and compression resilience

4.2.5 Surface Property

Table 4-10 Correlation coefficients between fabric thickness and surface parameters

	MIU(w)	MIU(c)	MMD(w)	MMD(c)	SMD(w)	SMD(c)
Thickness	-0.001	*0.204	0.133	0.181	-0.013	-0.19
Sig.	0.990	0.037	0.177	0.065	0.899	0.052
N	105	105	105	105	105	105

Where, (w); wale direction (c); course direction
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Similar to the results obtained from tensile property, there is no significant relationship between fabric thickness and surface property that observed from Table 4-10. Using KES-F surface roughness instrument, the values were measured sensitively while the transducer had direct contact with sample surface. The frictional force was affected by the porosity characteristic of warp knitted fabrics. Contact pressure encountered unevenness due to the open structures of warp knitted fabrics. That increases the chance of unstable frictional force and outliers (Figure 4-14) occur eventually.

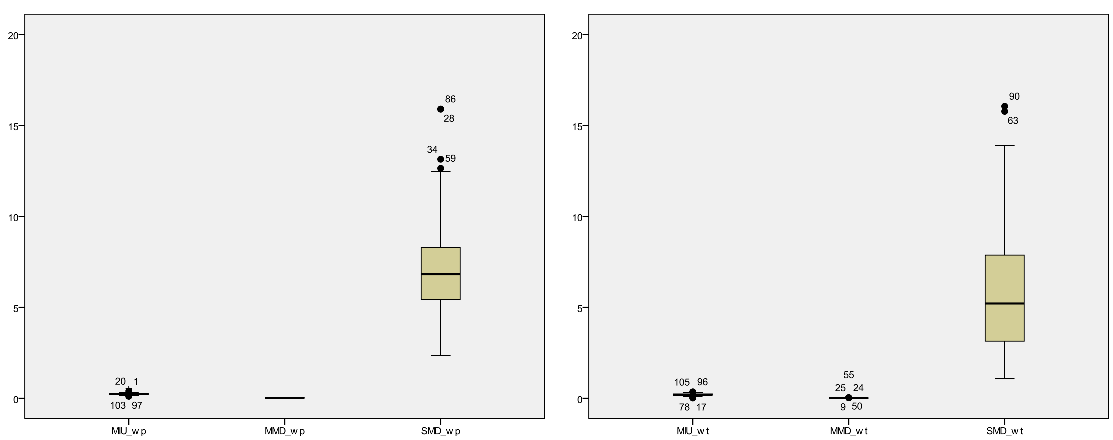

Figure 4-14 Box-plots showing outliers of surface property in wale and course directions

4.3 Effect of Fabric Hand Feel by Fabric Weight

4.3.1 Tensile Property

Table 4-11 Correlation coefficients between fabric weight and tensile parameters

	EMT(w)	EMT(c)	LT(w)	LT(c)	WT(w)	WT(c)	RT(w)	RT(c)
Weight	**-0.331	*-.247	0.007	0.015	**-0.331	**-0.293	**0.278	0
Sig.	0.001	0.011	0.945	0.880	0.001	0.002	0.004	0.999
N	105	105	105	105	105	105	105	105

Where, (w); wale direction (c); course direction
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

From Table 4-11, fabric weight shows a negative correlation with extensibility and tensile energy. Take wale direction for example, fabric weight is correlated to fabric extension R=-0.331 and tensile energy R=-0.331 with significant at 0.01 level. That means the smaller is the fabric weight, the higher will be the tensile extension and energy. It is because a heavier fabric has lower extensibility which leads lower tensile energy needed. Light warp knitted fabrics are easier to extend.

4.3.2 Shearing Property

Table 4-12 Correlation coefficients between fabric weight and shear parameters

	G(w)	G(c)	2HG(w)	2HG(c)	2HG5(w)	2HG5(c)
Weight	**0.585	**0.583	0.159	**0.283	**0.450	**0.567
Sig.	0.000	0.000	0.106	0.003	0.000	0.000
N	105	105	105	105	105	105

Where, (w); wale direction (c); course direction
** Correlation is significant at the 0.01 level (2-tailed).

Shear rigidity shows a positive correlation with fabric weight in Table 4-12, which the correlation coefficient between G and W is 0.585 (significant at 0.01 level). The heavier and bulkier is the fabric, the more difficult it is to shear paralleled in wale and course yarns. Figure 4-15 indicates that R^2=0.3632 which reflects moderate relationship between shear variable and weight per unit area.

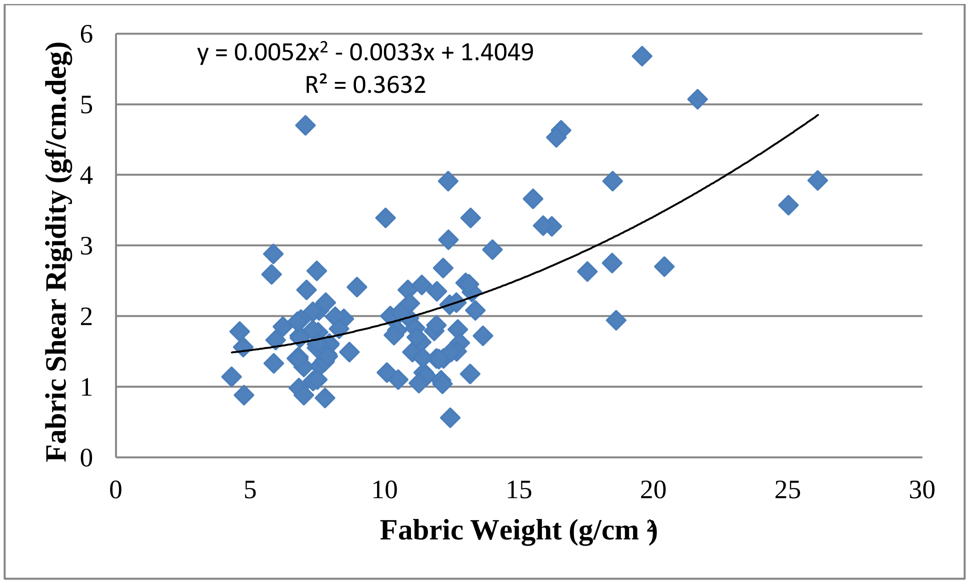

Figure 4-15 Relationship between fabric weight and shear rigidity

4.3.3 Bending Property

Generally the bending rigidity increases with an increase of fabric weight per unit area.

Table 4-13 Correlation coefficients between fabric weight and bending parameters

	B(w)	B(c)	2HB(w)	2HB(c)
Weight	**0.505	**0.511	**0.472	**0.482
Sig.	0.000	0.000	0.000	0.000
N	105	105	105	105

Where, (w); wale direction (c); course direction
** Correlation is significant at the 0.01 level (2-tailed).

As shown in Table 4-13, the correlation coefficient between the bending rigidity (wale and course direction) and fabric weight per unit area is 0.505 and 0.511. These results obtained are similar and indicates that fabric bending rigidity is to some extent determined by fabric weight.

4.3.4 Compression Property

Table 4-14 Correlation coefficients between fabric weight and compression parameters

	LC	WC	RC
Weight	*0.236	**0.494	**0.300
Sig.	0.015	0.000	0.002
N	105	105	105

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

For all fabrics tested, the correlation coefficient between fabric compression linearity (LC) and fabric weight (W) is relatively low at 0.236. The results from Table 4-14 indicate that there may be a tendency for fabric compression linearity to be raised with increasing fabric weight. The compression energy (WC) shows higher significant correlation with fabric weight that R=0.494 at 0.01 level. More energy was generated under the condition of increasing fabric weight with same sample size. The value of compression resilience (RC) thus becomes larger which is slightly related to fabric weight.

4.3.5 Surface Property

Table 4-15 Correlation coefficients between fabric weight and surface parameters

	MIU(w)	MIU(c)	MMD(w)	MMD(c)	SMD(w)	SMD(c)
Weight	0.062	-0.041	**0.276	**0.340	-0.127	**-0.447
Sig.	0.527	0.680	0.004	0.000	0.198	0.000
N	105	105	105	105	105	105

Where, (w); wale direction (c); course direction
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

There is a moderate linear relationship between the fabric roughness (SMD) or the surface texture and fabric weight observed from Table 4-15. These two properties have negative correlation coefficient which R=-0.447 with significant at 0.01 level. The relationship between fabric weight and SMD is shown in Figure 4-16. It indicates that the surface roughness increases when the fabric weight decreases. This could be caused by many lighter fabrics samples assembled in mesh fabric group. The porosity of mesh fabrics increases the surface roughness during the KES-F measurement.

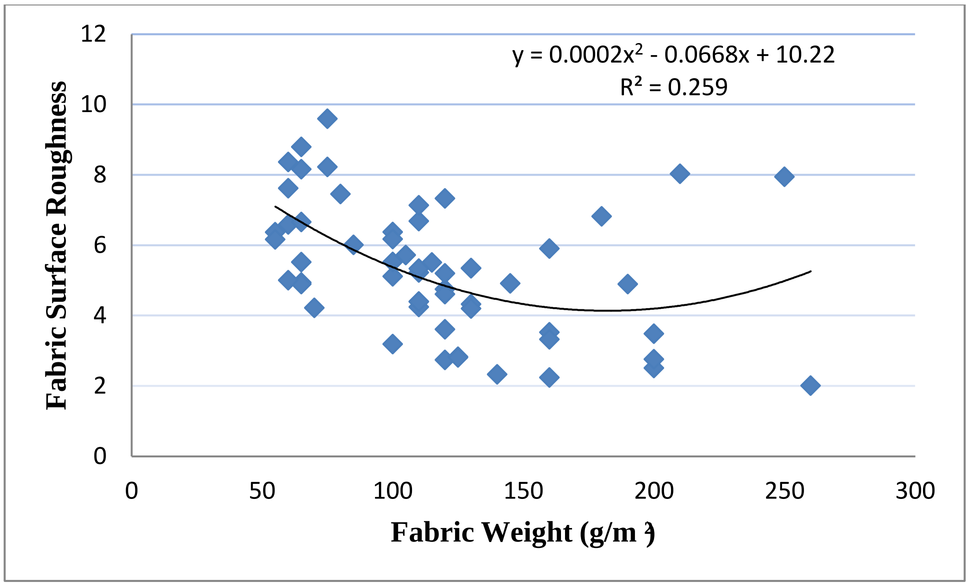

Figure 4-16 Relationship between fabric weight and surface roughness

4.4 Summary

In this part, the relationships between 17 mechanical properties obtained from KES-F system have been confirmed. The correlations of tensile extensibility, shear rigidity, bending behavior, compression energy and surface roughness were found to be significant in both wale and course measurement directions. Measured physical properties including fabric thickness (T) and weight per unit area (W) were also examined. Fabric thickness was found to be more correlated with KES-F low-stress mechanical parameters such as shear, bending and compression properties. Fabric weight was less correlated to mechanical variables with weak significant.

CHAPTER 5
RESULTS AND DISCUSSIONS ON FABRICS HAND ATTRIBUTES

5.1 Effect of Fabric Hand Feel from KES-F System

Primary Hand Value and Total Hand Value

Selected warp knitted fabrics were measured objectively by using KES-F instruments. The calculated primary hand values and the total hand value are analyzed by using the HESC translation equation for women's suiting materials, KN-201-MDY (refer to Chapter 3). The primary hand value for fabric stiffness ranges from 1.08 to 9.82 for all warp knitted fabrics. For the fabric smoothness and softness, the primary hand value ranges from 1.64 to 7.58 and from 0.51 to 7.98 respectively. The total hand value (THV) for these 105 fabrics ranges from 0.99 to 3.98.

To access the relationship between the fabric total hand value (THV) and the primary hand values for the warp knitted fabrics for women's suitings, The correlation matrix for the total hand value (THV) to the primary hand values calculated from the measurements using the KES-F system is shown in Table 5-1.

Table 5-1 Correlation matrix for primary hand values and total hand value (THV)

	Stiffness	Smoothness	Softness	SoftFeeling	THV	W	T
Stiffness	1						
Smoothness	**-0.603	1					
Softness	**-0.286	**0.853	1				
SoftFeeling	**-0.641	**0.957	**0.805	1			
THV	-0.124	**0.834	**0.907	**0.736	1		
W	**0.821	**-0.316	-0.015	**-0.390	0.111	1	
T	**0.611	-0.042	**0.406	-0.058	**0.365	**0.687	1

Where, W; weight T; Thickness
** Correlation is significant at the 0.01 level (2-tailed).

The results from Table 5-1 show that the primary hand values of smoothness, softness and soft feeling are directly related to fabric total hand value with R=0.834 , 0.907 and 0.736 respectively, which are significant at 0.01 level. This means that the primary hand value of smoothness and softness for warp knitted fabrics make a significant positive contribution to the fabric total hand value that calculated by KES-F equation. The relationships of THV to fabric smoothness and softness are shown in Figure 5-1 and 5-2.

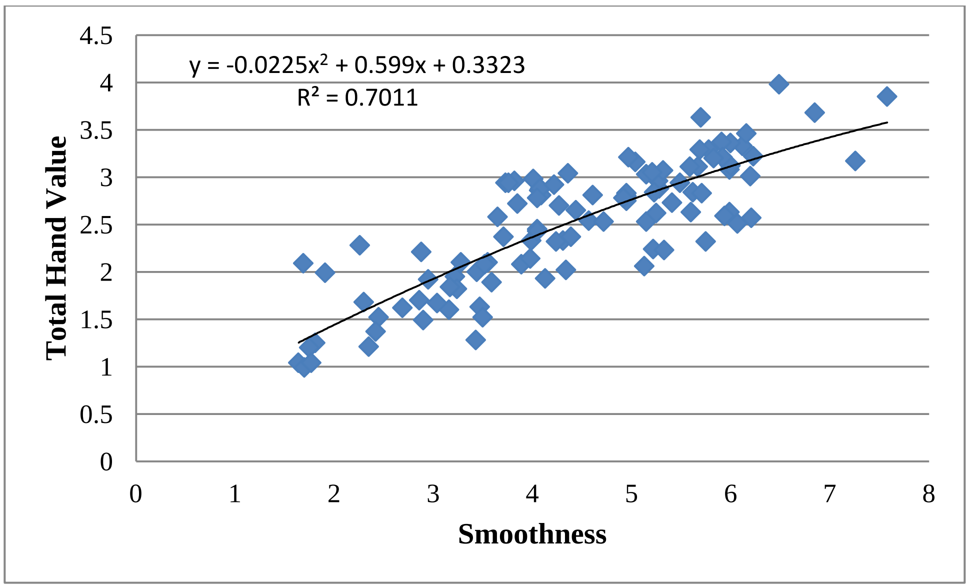

Figure 5-1 Relationship between THV and primary hand value of smoothness

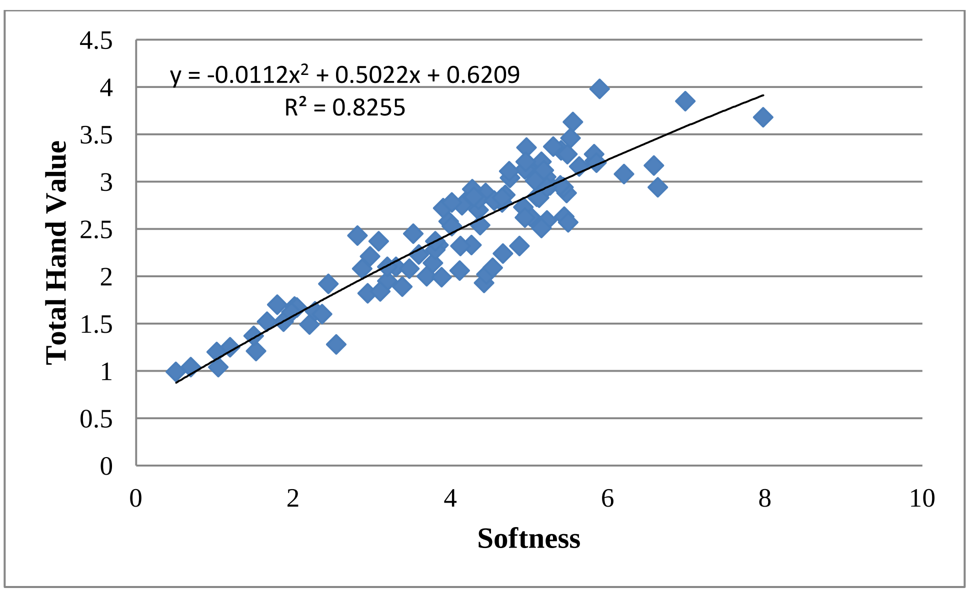

Figure 5-2 Relationship between THV and primary hand value of softness

Depending on Table 5-1, the fabric stiffness of warp knitted fabric is highly correlated to the fabric weight and thickness. The correlation coefficient between fabric stiffness and fabric weight and thickness is 0.821 and 0.611 respectively. The relationships of the fabric stiffness to fabric weight and thickness are shown in Figure 5-3 and 5-4 respectively. It represents that the heavier and thicker is the fabric, fabrics will be stiffer consequently.

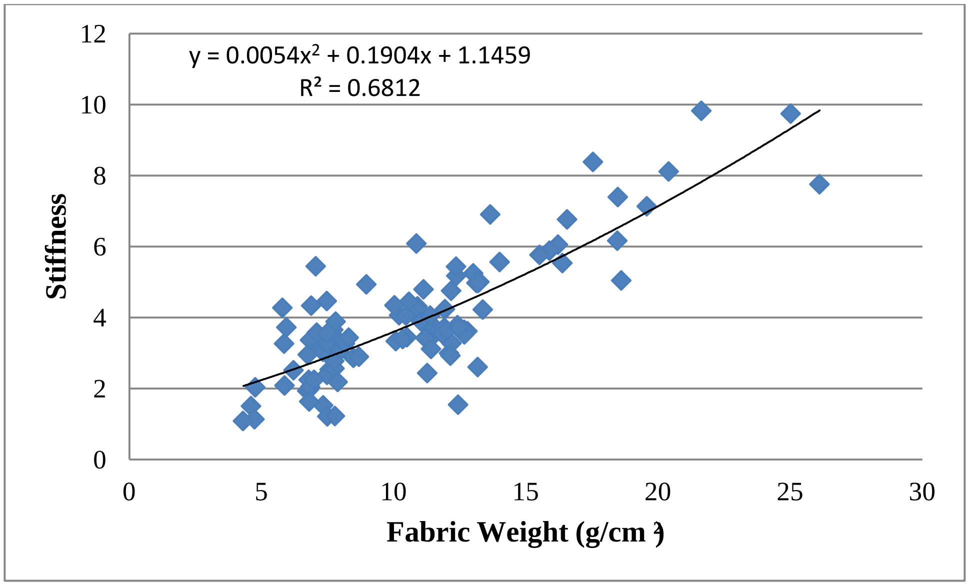

Figure 5-3 Relationship between fabric weight and hand value of stiffness

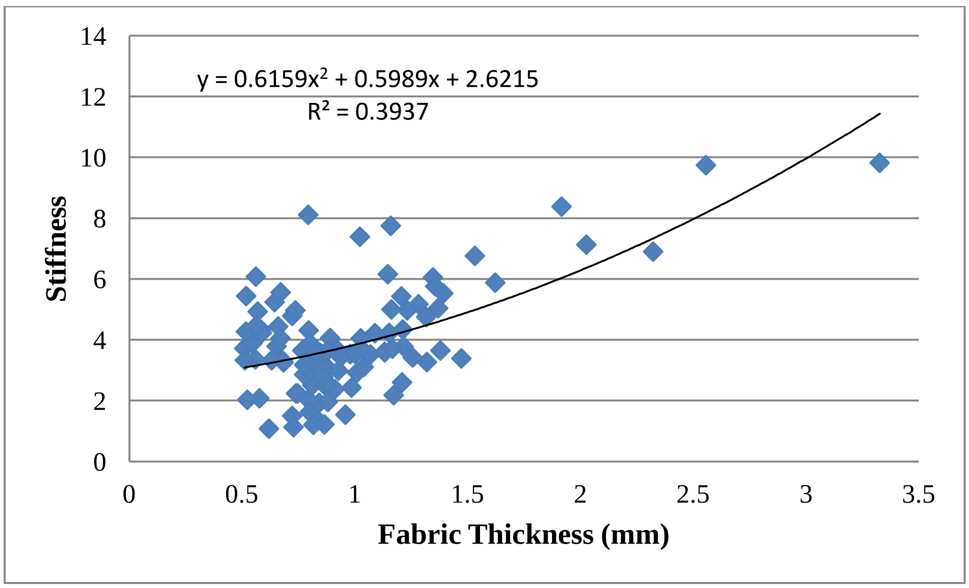

Figure 5-4 Relationship between fabric thickness and hand value of stiffness

5.2 Effect of Fabric Hand Feel from PhabrOmeter System

Fabric Hand Properties on Different Group of Weight

The PhabrOmeter System was conducted to measure the hand value of stiffness, smoothness, softness and fabric drape; which are similar to the primary hand values of the KES-F System. Fabric results were separately examined by various fabric types depending on fabric linear density range. To explore the relationship between the fabric hand attribute and weight and thickness of all 105 warp knitted fabrics, the correlation matrix of super light fabrics is generated by SPSS as shown in Table 5-2.

5.2.1 Super Light Fabrics

Table 5-2 Relationship between fabric weight, thickness and super light fabric hand attributes

	Stiffness	Smoothness	Softness	Drape	W	T
Stiffness	1					
Smoothness	**-0.633	1				
Softness	**0.813	**-0.901	1			
Drape	**-0.613	0.107	-0.188	1		
W	-0.281	*0.522	*-0.528	-0.434	1	
T	0.388	-0.256	0.136	**-0.626	0.199	1

Where, W; weight T; Thickness
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

In Table 5-2, there is positive correlation between fabric weight and fabric smoothness. The coefficient R=0.522 with significant at 0.05 level shows that fabric weight affects the hand value of smoothness. The heavier is the fabric, the smoother it will become. In other words, a heavier fabric will have a smoother fabric hand feel.

Fabric softness is negatively correlated with fabric weight R=-0.528 at 0.05 significant level. That implies the heavier the fabric, the less softness it will become.

No significant correlation is found between fabric thickness and primary hand values. However, a strong correlation occurred between fabric thickness and fabric drape. Fabric drape is one of the important properties when evaluating fabric hand feel. Using the PhabrOmeter System, the fabric drape is significantly affected by fabric thickness. Drape is a fabric's ability to form pleasing folds when bent under its own weight. A thicker fabric may increases the difficulty of bending behavior of fabrics. The correlation coefficient between fabric drape and thickness is R=-0.626.

5.2.2 Light Fabrics

Table 5-3 Relationship between fabric weight, thickness and light fabric hand attributes

	Stiffness	Smoothness	Softness	Drape	W	T
Stiffness	1					
Smoothness	**-0.421	1				
Softness	-0.074	**-0.295	1			
Drape	**-0.898	*0.290	-0.08	1		
W	**-0.335	0.012	*0.284	**0.297	1	
T	-0.103	0.043	0.011	0.086	**0.388	1

Where, W; weight T; Thickness
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

In Table 5-3, there is negative correlation between fabric weight and fabric stiffness. The coefficient R=-0.335 with significant at 0.01 level shows that fabric weight affects the hand value of stiffness. The lighter is the fabric, the stiffer it will become. In other words, a heavier fabric will have a softer fabric hand feel.

In this group of fabrics, there is no correlation between fabric thickness and the properties obtained from PhabrOmeter System.

5.2.3 Medium to Heavy Fabrics

Table 5-4 Relationship between fabric weight, thickness and medium fabric hand attributes

	Stiffness	Smoothness	Softness	Drape	W	T
Stiffness	1					
Smoothness	*-0.741	1				
Softness	*0.714	**-0.974	1			
Drape	**-0.814	**0.940	**-0.954	1		
W	-0.3	0.198	-0.023	0.124	1	
T	-0.541	0.5	-0.604	0.594	-0.494	1

Where, W; weight T; Thickness
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

In Table 5-4, there is no significant correlation between fabric weight, thickness and the hand values. The different instruments used in these two evaluations may affect the results. The types of warp knitted fabrics in this group (brushed mesh, brushed tricot and space fabrics) also influence the results. These fabrics are not suitable to examine under KES-F and PhabrOmeter instruments. These two measurement methods are designed for thinner and lighter fabrics and there is lack of compatibility between the fabric type and the equation of these objective evaluation systems.

5.3 Effect of Fabric Hand Feel from Subjective Measurement

The panel of twenty-five judges was invited to conduct the subjective hand assessments on all 105 warp knitted fabrics. The results are shown in Appendix 3.

Similar to the analysis on KES-F and PhabrOmeter data, physical properties of sample fabrics are examined whether there is any correlation with the subjective hand values. Fabric weight and thickness are used to correlate with stiffness, smoothness, softness and total hand values by applying SPSS single linear regression method. Relationships are shown in Table 5-5.

Table 5-5 Relationship between fabric weight, thickness and fabric hand attributes from subjective measurement

	Stiffness	Smoothness	Softness	THV	W	T
Stiffness	1					
Smoothness	**-0.601	1				
Softness	**-0.953	**0.631	1			
THV	**-0.839	**0.770	**0.871	1		
W	**0.740	-0.106	**-0.739	**-0.492	1	
T	**0.730	**-0.464	**-0.755	**-0.675	**0.686	1

Where, W; weight T; Thickness
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

The results from Table 5-5 show that THV is positively correlated with fabric smoothness and softness with R=0.77 and 0.871 at 0.01 significant level, but negatively correlated with fabric stiffness with R=-0.839. This means that the primary hand value of smoothness and softness for these warp knitted fabrics as assessed by the judges makes a significant positive contribution to the fabric total hand value. For the fabric primary hand value of stiffness, the result means that the smaller is the stiffness, the higher is the total hand value as assessed by the judges. The relationships between fabric stiffness, smoothness, softness and total hand value are shown as Figure 5-5, 5-6 and 5-7 respectively.

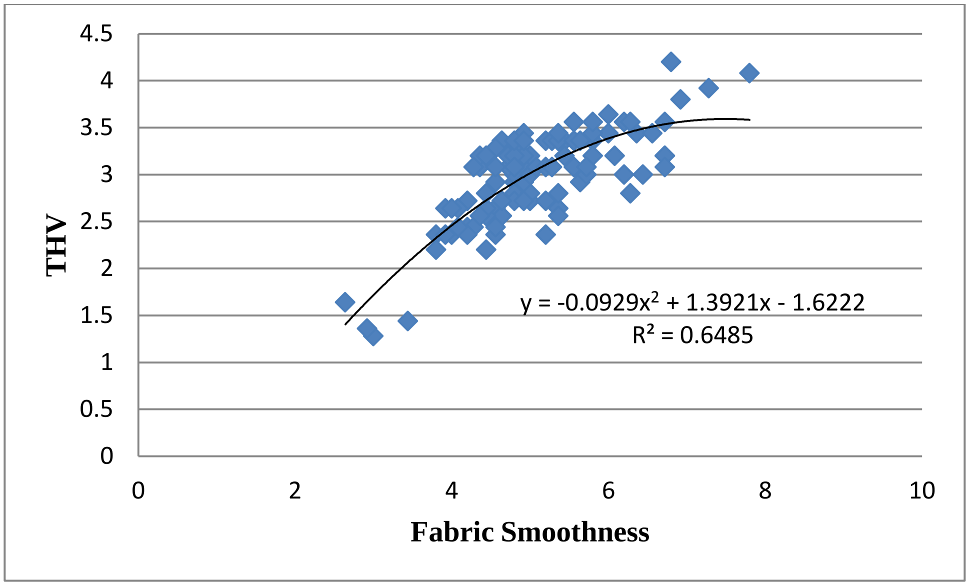

Figure 5-5 Relationship between subjective smoothness and THV

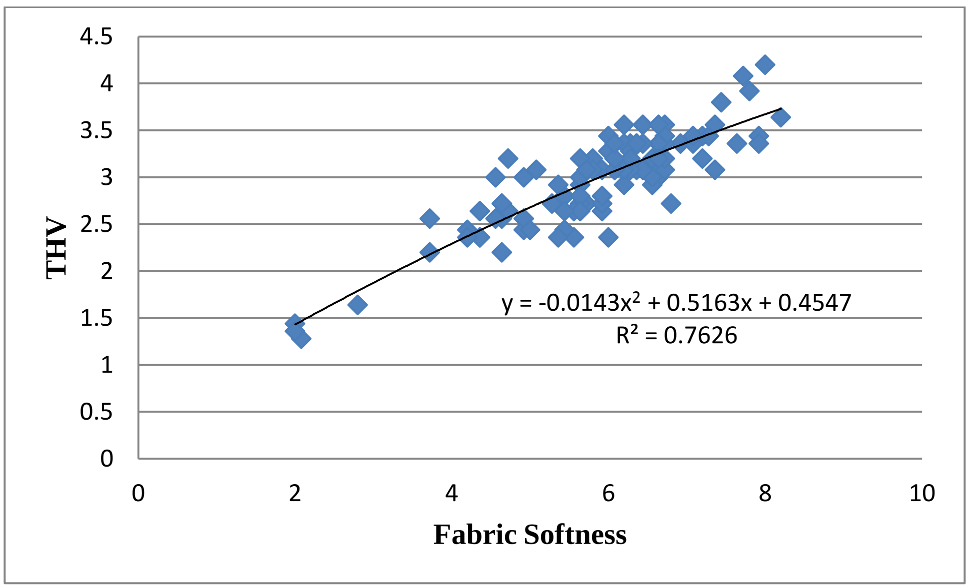

Figure 5-6 Relationship between subjective softness and THV

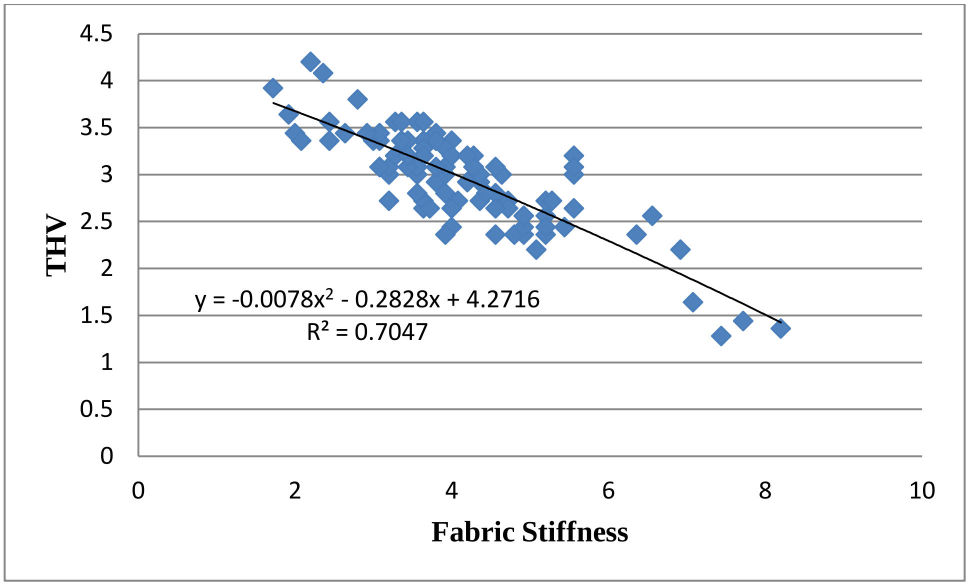

Figure 5-7 Relationship between subjective stiffness and THV

On the hand of physical properties, fabric weight and thickness show positive effect on stiffness and negative effect on smoothness, softness and THV values. For the hand value of fabric stiffness (Figure 5-8), correlations with weight and thickness are high that R=0.74 and 0.73 respectively. The R value implies that the lighter and thinner of the fabrics, the less stiffness the fabrics that the judges experience. For fabric smoothness (Figure 5-9), weight does not play any significant role in affecting it but thickness does. R=-0.464 shows moderate meaning of the thinner the fabrics-the smoother the specimens. For softness (Figure 5-10) and total hand value (Figure 5-11), fabric weight and thickness both play negative role which R=-0.73, -0.492, -0.75 and -0.675 respectively. The lower the fabric weight and thickness, the higher the softness and the total hand value for these warp knitted fabrics. On the whole, the judges tend to be favorable in light and thin warp knitted fabrics.

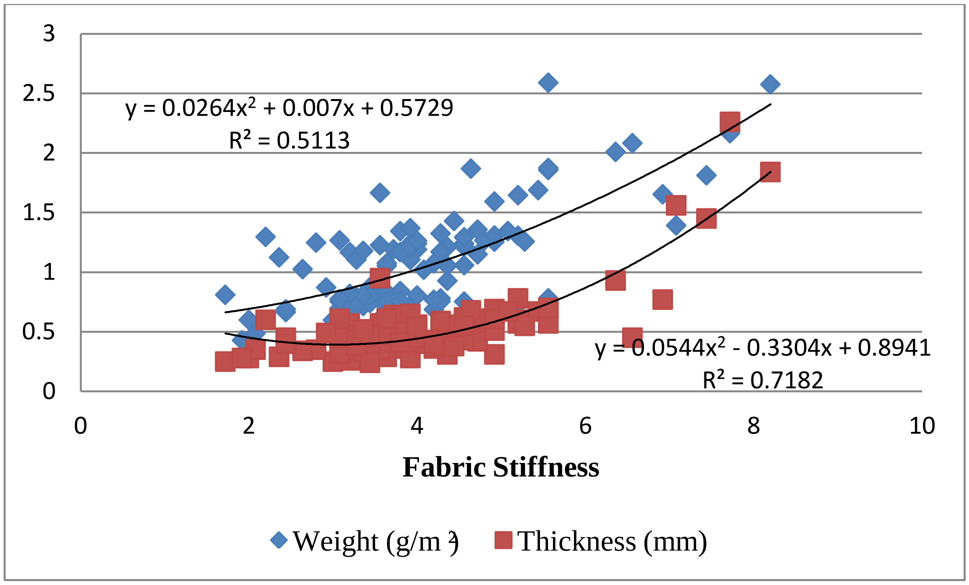

Figure 5-8 Correlations between fabric stiffness, weight and thickness

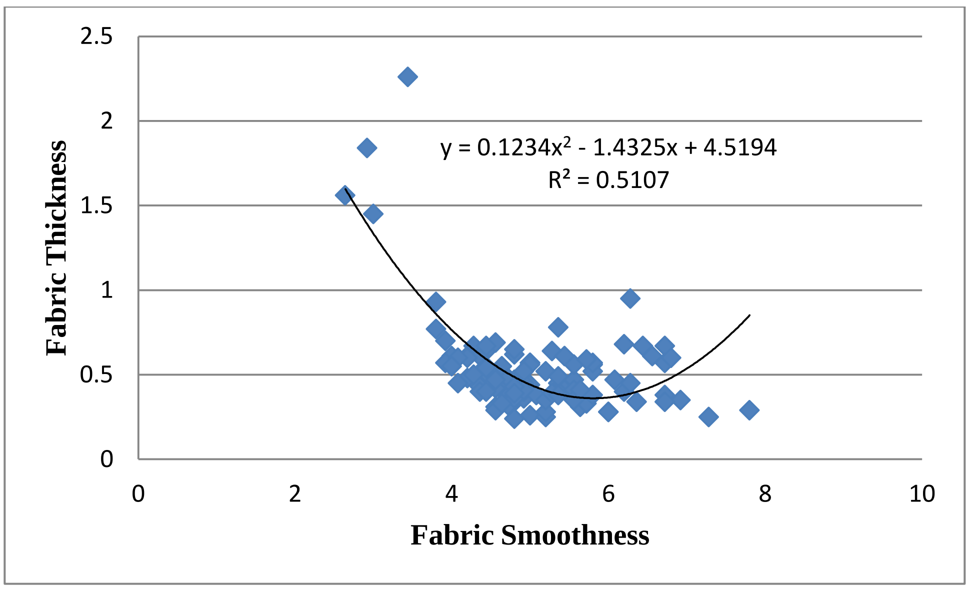

Figure 5-9 Correlations between fabric smoothness and thickness

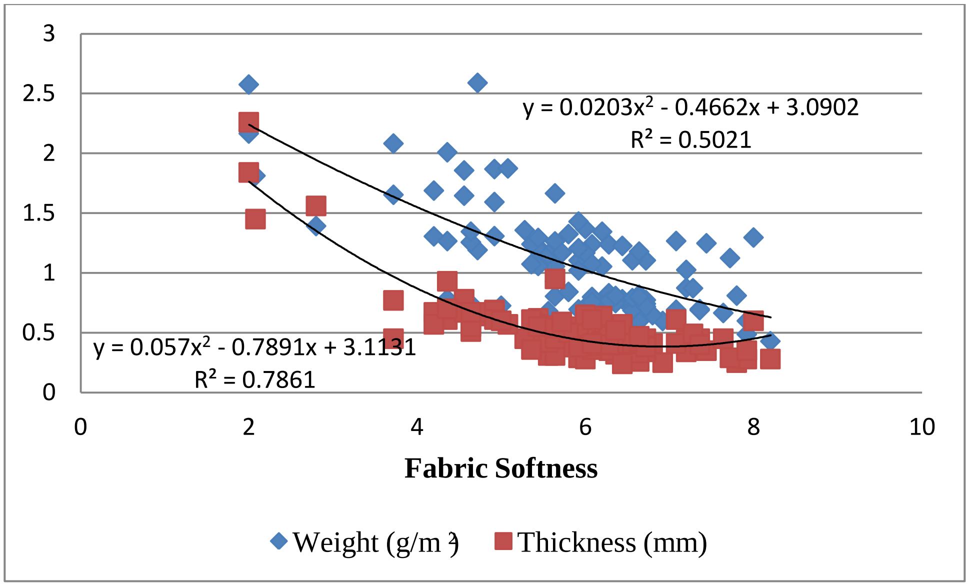

Figure 5-10 Correlations between fabric softness, weight and thickness

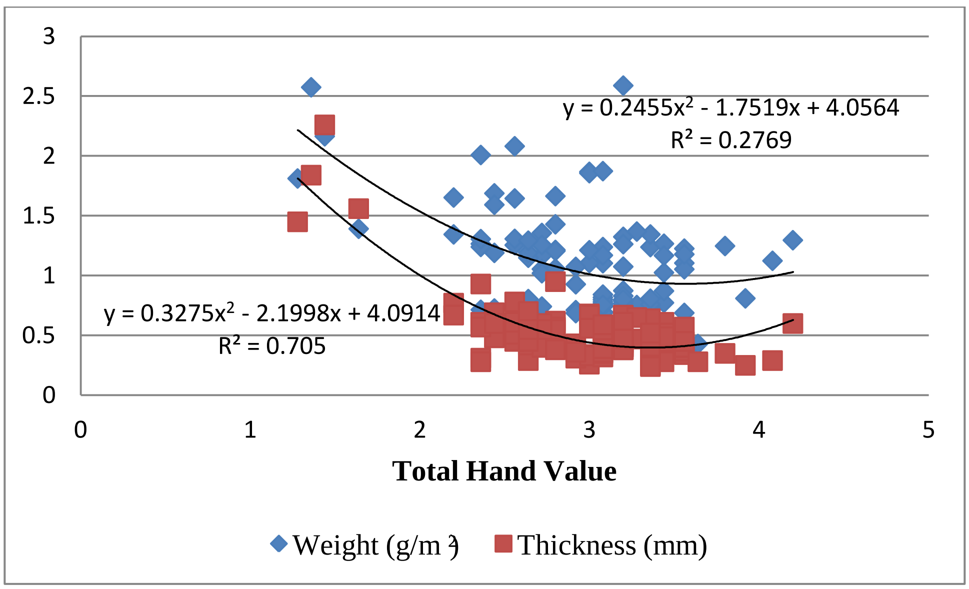

Figure 5-11 Correlations between total hand value, fabric weight and thickness

5.4 Comparative Study of Fabric Hand Properties

5.4.1 KES-F System versus PhabrOmeter System

Super Light Fabrics

The distinctions between two measurement methods are obvious. KES-F system measures the surface parameters with clear physical interpretation of test fabrics.

PhabrOmeter in contrast performs test procedures that believed to simulate hand feeling process. Physical meanings of forces recorded are only forces that needed to push the fabrics through designed metal hole. KES-F system subsequently calculates predicted smoothness value based on formulas obtained from regression analyses. PhabrOmeter in the other way directly calculates smoothness value from recorded data using a statistical pattern recognition formula. Therefore, their correlation analysis is performed to find whether there is relationship between these two measurements. Correlation analyses are conducted according to the linear density as assessed by the PhabrOmeter system. Results are shown in Table 5-6, Table 5-7 and Table 5-8.

Table 5-6 Correlation results between KES-F and PhabrOmeter stiffness value of super light fabrics

		Stiffness (KES-F)
Stiffness (PhabrOmeter)	Pearson Correlation	-0.566*
	Sig. (2-tailed)	0.014
	N	18

Table 5-7 Correlation results between KES-F and PhabrOmeter smoothness value of super light fabrics

		Smoothness (KES-F)
Smoothness (PhabrOmeter)	Pearson Correlation	-0.759**
	Sig. (2-tailed)	0.000
	N	18

Table 5-8 Correlation results between KES-F and PhabrOmeter softness value of super light fabrics

		Softness (KES-F)
Softness (PhabrOmeter)	Pearson Correlation	0.733**
	Sig. (2-tailed)	0.001
	N	18

In Table 5-6 and 5-7, there are negative correlations of fabric stiffness and smoothness between KES-F and PhabrOmeter system, R=-0.566 and -0.759 respectively. In contrast, fabric softness of KES-F System is positively correlated to that of PhabrOmeter R=0.733 with significant at 0.01 level.

The complex correlation between these two objective measurements may attribute to the construction of warp knitted fabrics in super light fabric group. These types are ultra micro mesh, mesh, shiny mesh and brushed mesh. The range of weight is from 45 to 80g/m². Such differences affect the consistency of the results obtained from the instruments.

Light Fabrics

Correlation analysis of fabric smoothness and softness value between KES-F and PhabrOmeter shows significant correlation. Correlation statistics of smoothness value measured by these two instruments is shown in Table 5-10 and 5-11. Correlation significant p value is 0.001 and 0.003<0.05, which means significant relations are found between smoothness and softness value measured by KES-F and PhabrOmeter. The linear correlation between smoothness values is R=0.388 and 0.333. It states that these two measurement methods gave positively related smoothness and softness values of the warp knitted fabrics. Fabrics with higher value obtained from KES-F tend to show high scores in PhabrOmeter evaluation, implying these fabrics have better hand feel.

Fabric stiffness value between KES-F and PhabrOmeter also shows significant correlation between these two measurement methods. As shown in Table 5-9, correlation coefficient between two methods is 0.255, significant p value is 0.026<0.05. It can be explained that these two evaluation methods have positive relationship on stiffness values of the warp knitted fabrics. Both measurements indicates fabric stiffness as the higher the stiffness value – the harder the fabric.

Table 5-9 Correlation results between KES-F and PhabrOmeter stiffness value of light fabrics

		Stiffness (KES-F)
Stiffness (PhabrOmeter)	Pearson Correlation	0.255*
	Sig. (2-tailed)	0.026
	N	76

Table 5-10 Correlation results between KES-F and PhabrOmeter smoothness value of light fabrics

		Smoothness (KES-F)
Smoothness (PhabrOmeter)	Pearson Correlation	0.388**
	Sig. (2-tailed)	0.001
	N	76

Table 5-11 Correlation results between KES-F and PhabrOmeter softness value of light fabrics

		Softness (KES-F)
Softness (PhabrOmeter)	Pearson Correlation	0.333**
	Sig. (2-tailed)	0.003
	N	76

<u>Medium to Heavy Fabrics</u>

Although there is no significant relationship between the physical properties and fabric hand values, it is necessary to check whether KES-F system is correlated with PhabrOmeter system in determining the fabric hand attributes.

Table 5-12 Correlation results between KES-F and PhabrOmeter stiffness value of medium to heavy fabrics

		Stiffness (KES-F)
Stiffness (PhabrOmeter)	Pearson Correlation	-0.684*
	Sig. (2-tailed)	0.042
	N	9

Table 5-13 Correlation results between KES-F and PhabrOmeter smoothness value of medium to heavy fabrics

		Smoothness (KES-F)
Smoothness (PhabrOmeter)	Pearson Correlation	-0.67*
	Sig. (2-tailed)	0.049
	N	9

Table 5-14 Correlation results between KES-F and PhabrOmeter softness value of medium to heavy fabrics

		Softness (KES-F)
Softness (PhabrOmeter)	Pearson Correlation	0.369
	Sig. (2-tailed)	0.328
	N	9

In Table 5-12 and Table 5-13, stiffness and smoothness value between KES-F and PhabrOmeter system show negative significant correlation. The correlation significant R=-0.684 and -0.67 and p value is 0.042 and 0.049<0.05, which represents that moderate significant relation is found between the KES-F and PhabrOmeter system.

Unlike the smoothness and stiffness value, softness value (Table 5-14) between KES-F and PhabrOmeter system shows no significant correlation. The correlation significant p value is 0.328, which represents that no significant relation is found between the KES-F and PhabrOmeter system.

5.4.2 KES-F System versus Subjective Measurement

Table 5-15 Correlation results between KES-F and subjective stiffness value

		Stiffness (KES-F)
Stiffness (Subjective)	Pearson Correlation	0.768**
	Sig. (2-tailed)	0.000
	N	105

Correlation analysis of fabric stiffness value between subjective and KES-F system shows significant correlation between these two measurement methods. Correlation statistics of stiffness value measured by these two instruments is shown in Table 5-15. Correlation significant p value is $0.000<0.05$, which means a significant relation is found between stiffness value measured by subjective and KES-F methods. The linear correlation between stiffness values is R=0.768. It states that these two measurement methods give positively related stiffness values of the warp knitted fabrics. Fabrics with higher value obtained from subjective test tend to show high scores in KES-F evaluation. The relationship $R^2=0.6197$ in Figure 5-12 reflects the strong coefficient between KES-F and subjective test results.

This finding is conformed to Alimaa's investigation (Alimaa et al., 2000). There was a high possibility to obtain significant correlation in measuring fabric thickness, compressibility and bending rigidity. Such sensory assessment perceived by subjective touch and the corresponding mechanical parameters measured by KES-F instruments were essentially the same. It proves that fabric stiffness has an objective quantitative basis in subjective measurement and they are always well correlated in these cases.

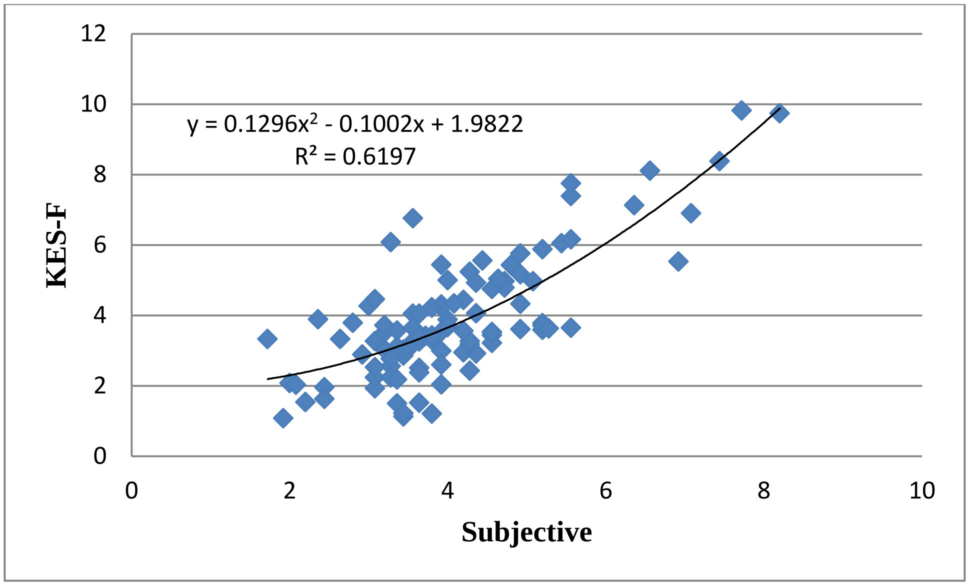

Figure 5-12 Relationship of fabric stiffness between subjective and KES-F system

However, the primary hand value of smoothness and softness and the total hand value from subjective evaluation shows a very small negative correlation with those values of KES-F system (with R=-0.041, -0.086 and -0.111), which results are shown in Table 5-16, Table 5-17 and Table 5-18. These results mean that the subjective assessments by the judges of fabric smoothness and softness are in poor agreement with the calculations made using the KES-F measurements, at the end also interrupt the agreement of total hand value.

Table 5-16 Correlation results between KES-F and subjective smoothness value

		Smoothness (KES-F)
Smoothness (Subjective)	Pearson Correlation	-0.041
	Sig. (2-tailed)	0.679
	N	105

Table 5-17 Correlation results between KES-F and subjective softness value

		Softness (KES-F)
Softness (Subjective)	Pearson Correlation	-0.086
	Sig. (2-tailed)	0.381
	N	105

Table 5-18 Correlation results between KES-F and subjective total hand value

		THV (KES-F)
THV (Subjective)	Pearson Correlation	-0.111
	Sig. (2-tailed)	0.258
	N	105

5.4.3 PhabrOmeter System versus Subjective Measurement

To find the relationship between subjective measurement and PhabrOmeter System, the linear density group in Chapter 3 cannot be applied on the assessed hand value by judges. An overall correlation matrix is conducted and the results are shown in Table 5-19, Table 5-20 and Table 5-21 as below.

For the fabric stiffness value (Table 5-19), there is no significant correlation found between subjective test and PhabrOmeter System. This may due to the difference of assessed hand results from these two methods. As the range of stiffness value from PhabrOmeter is so small, insufficient compatibility of two systems occurred and lack of correlation would eventually appear.

Table 5-19 Correlation results between PhabrOmeter and subjective stiffness value

		Stiffness (PhabrOmeter)
Stiffness (Subjective)	Pearson Correlation	0.009
	Sig. (2-tailed)	0.925
	N	105

On the other hand, there is a negative correlation of smoothness value between subjective and PhabrOmeter system. The result is shown in Table 5-20 and R=-0.312 at 0.01 significant level. Fabrics with higher smoothness value obtained from subjective evaluation tend to show lower scores in PhabrOmeter evaluation. This relationship showed in Figure 5-13 agrees on the definition of subjective smoothness value (higher the value, better the smoothness property) and the PhabrOmeter smoothness value (smaller the value, better the smoothness property).

Table 5-20 Correlation results between PhabrOmeter and subjective smoothness value

		Smoothness (PhabrOmeter)
Smoothness (Subjective)	Pearson Correlation	-0.312**
	Sig. (2-tailed)	0.001
	N	105

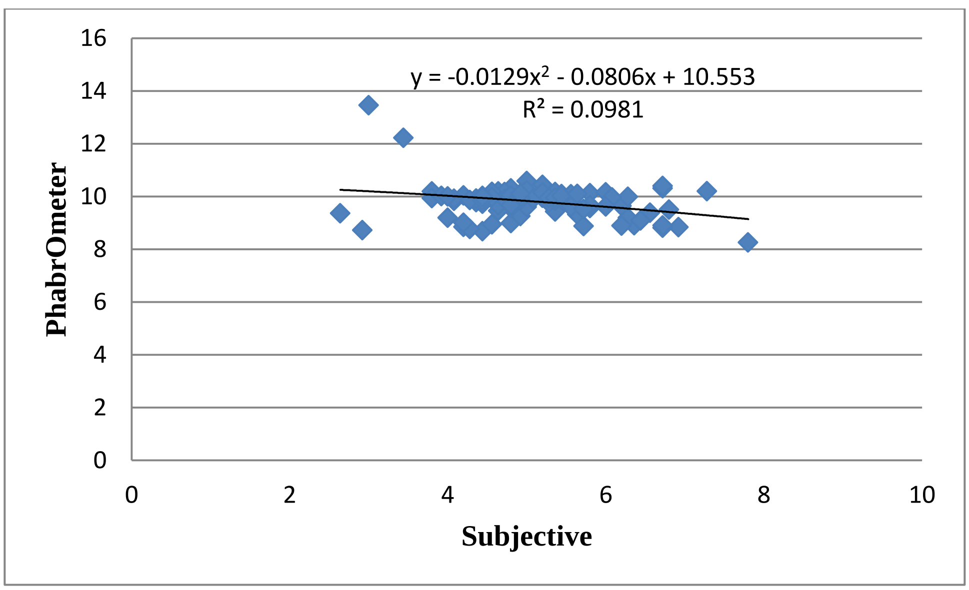

Figure 5-13 Relationship of fabric smoothness between subjective and PhabrOmeter system

In contrast to the smoothness value, there is a positive correlation between subjective and PhabrOmeter evaluation (Table 5-21). That is contradictory to the principle definition of the two tests. The only reason may attribute to the complexity deviation of judges' assessment on the warp knitted fabrics.

Table 5-21 Correlation results between PhabrOmeter and subjective softness value

		Softness (PhabrOmeter)
Softness (Subjective)	Pearson Correlation	0.300**
	Sig. (2-tailed)	0.002
	N	105

5.4 Summary

This chapter reported two important calculations of subjective assessment and objective measurements in fabric hand for warp knitted fabrics. Various fabric evaluation systems were explored to find any effect on fabric hand attributes. In KES-F system, hand properties including primary hand values and total hand value were indicated to be correlated to warp knitted fabric thickness and weight. For PhabrOmeter system, warp knitted samples were separated in groups according to its linear density. Hand attributes showed correlation with physical properties in some extends. The results of subjective measurement were also discovered as significant with fabric weight and thickness.

Comparative studies were also conducted in this chapter. The results obtained from subjective assessments were compared with calculated values obtained from the KES-F and PhabrOmeter system. It was found that a strong correlation existed on the stiffness value. However, there is no relationship between fabric smoothness, softness and total hand value. The situation is opposite in the correlation between subjective and PhabrOmeter system. Poor relationship exists for fabric stiffness and odd correlation occurred for fabric smoothness and softness.

CHAPTER 6

MULTIPLE LINEAR REGRESSION ANALYSIS FOR FABRIC HAND

6.1 Stepwise Multiple Regression Analysis of Variance on Mechanical Properties for Warp Knitted Fabrics

The objective measurements using the KES-F system and subjective assessment of hand values of warp knitted fabrics as discussed in Chapter 5 have shown that primary hand values of stiffness smoothness and softness are closely related to the total hand value. The subjectively assessed hand value (stiffness) is strongly correlated with the value calculated from KES-F measurements.

The hand values calculated using the HESC translation equations cannot be directly applied to the Hong Kong textile and apparel supply chain because of the difference in fabric subjective handle assessments between the expert judges from different countries especially Japan. The fabric mechanical data obtained from the KES-F instruments nevertheless provide a valuable tool to understand the relationships between fabric properties (tensile, shear, bending, compression and surface properties) and the fabric hand values.

In this chapter, the relationship of each fabric mechanical property obtained from the KES-F instruments to the fabric primary hand values is examined by means of multiple stepwise mechanical block regression analysis. This technique can identify the most significant fabric mechanical property in the regression equation to explain the fabric hand values for these warp knitted fabrics. The results would facilitate the data interpretation and allow the industries to engineer a particular fabric mechanical block in terms of objective measurement data for the purposes of process and product control and development.

6.2 Fabric Mechanical Properties Obtained from KES-F Measurements

The expert subjective assessment of primary hand values and total hand value for warp knitted fabrics of stiffness, smoothness and softness can be related to low-stress fabric mechanics in terms of tensile, bending, shear, compression and surface roughness as measured by the KES-F instruments. The measured fabric mechanical parameters from the KES-F instruments can be grouped under these five mechanical blocks as shown in Table 6-1.

Table 6-1 Fabric mechanical blocks from KES-F measurement

Block Number	**Name**	**Mechanical Parameters**
N1	Tensile	EMT, LT, WT, RT
N2	Bending	B, 2HB
N3	Shear	G, 2HG, 2HG5
N4	Compression	LC, WC, RC
N5	Surface	MIU, MMD, SMD

(The definition and units for all parameters are quoted in Table 2-2)

In order to understand which of the fabric mechanical blocks have the major effect on each of the primary hand values, the mechanical properties of all 105 warp knitted fabrics are correlated with each primary hand value by means of stepwise regression analysis.

6.3 Stepwise Multiple Regression Analysis on Fabric Hand Values

Multiple regression analysis is a statistical technique that can be used to analyze the relationship between a single dependent (criterion) variable and several independent (predictor) variables (Hair, 2000). Each independent variable is weighted by the regression analysis procedure to ensure maximal prediction from the set of the independent variables. The weightings denote the relative contribution of the independent variables to the overall prediction and facilitate interpretation as to the influence of each variable in making the prediction.

6.3.1 Fabric Stiffness to KES-F Mechanical Blocks

Table 6-2 shows that the correlation matrix of the present analysis between the five fabric mechanical blocks to stiffness.

Table 6-2 Correlation matrix between mechanical blocks and stiffness/firmness

	N1	N2	N3	N4	N5	Stiffness
N1	1					
N2	*-0.214	1				
N3	**-0.418	**0.614	1			
N4	0.139	**0.472	*0.24	1		
N5	-0.074	0.062	*-0.196	-0.018	1	
Stiffness	**-0.264	**0.596	**0.717	*0.248	**-0.29	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Using the stepwise mechanical block regression analysis, the five fabric mechanical blocks were selected and tested for their significance to the regression equation. The results are shown in Table 6-3.

Table 6-3 Stepwise regression analysis for stiffness hand value

Model	Variables Entered	Method
1	Shear (N3)	Stepwise (Criteria: Probability-of-F-to-enter ≤ 0.05, Probability-of-F-to-remove ≥.100).
2	Bending (N2)	Stepwise (Criteria: Probability-of-F-to-enter ≤ 0.05, Probability-of-F-to-remove ≥ .100).
3	Surface (N5)	Stepwise (Criteria: Probability-of-F-to-enter ≤ 0.05, Probability-of-F-to-remove ≥ .100).

Table 6-3 shows that the first fabric mechanical block enters into the regression equation is N3 (Shear), followed by N2 (Bending) and N5 (Surface properties). These three fabric mechanical blocks are selected by stepwise regression and the summary of the models is shown in Table 6-4.

Table 6-4 Summary of each model selected by stepwise regression analysis

Model	Variable	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	Shear	0.717	0.514	0.509	1.21288
2	Bending	0.744	0.553	0.544	1.16847
3	Surface	0.771	0.595	0.583	1.11797

Table 6-4 shows the summary of three fabric mechanical blocks entered into the regression equation. The first model with only one fabric mechanical block (N3) entered into the equation gives R^2 equal to 0.509. The second model with both N3 and N2 added into the equation, gives R^2 equal to 0.544. The third model with N3, N2 and N5 added into the equation, gives R^2 equal to 0.583.

Table 6-4 shows clearly that the first fabric mechanical block (N3) plays a significant role in Stiffness. Stiffness is defined as “the fabric having compact weaving density and woven by springy and elastic yarn makes this feeling strong” (Kawabata, 1980). This stiffness feeling is strongly correlated to shear rigidity. Shear is an important property in fabric tailoring. The next fabric mechanical block contributing to stiffness is bending (N2). Both blocks 3 and 2 together can explain over 50% (R^2=0.544) of primary hand value stiffness. These two fabric mechanical blocks are important for the explanation of stiffness in warp knitted fabrics.

6.3.2 Fabric Smoothness to KES-F Mechanical Blocks

Table 6-5 Correlation matrix between mechanical blocks and smoothness

	N1	N2	N3	N4	N5	Smoothness
N1	1					
N2	*-0.214	1				
N3	**-0.418	**0.614	1			
N4	0.139	**0.472	*0.24	1		
N5	-0.074	0.062	*-0.196	-0.018	1	
Smoothness	0.083	**-0.324	**-0.391	*0.244	0.128	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Table 6-5 shows the correlation matrix between mechanical blocks and smoothness. Table 6-6 shows that fabric mechanical block N3 (shear properties) was entered first into the regression equation followed by N4 (compression), N2 (bending) and N1 (tensile).

Table 6-6 Stepwise regression analysis for smoothness hand value

Model	**Variables Entered**	**Method**
1	Shear (N3)	Stepwise (Criteria: Probability-of-F-to-enter ≤ 0.05, Probability-of-F-to-remove ≥.100).

2	Compression (N4)	Stepwise (Criteria: Probability-of-F-to-enter ≤ 0.05, Probability-of-F-to-remove ≥.100).
3	Bending (N2)	Stepwise (Criteria: Probability-of-F-to-enter ≤ 0.05, Probability-of-F-to-remove ≥.100).
4	Tensile (N1)	Stepwise (Criteria: Probability-of-F-to-enter ≤ 0.05, Probability-of-F-to-remove ≥.100).

The explanation power (R^2) for each mechanical block entered into the equation is shown in Table 6-7.

Table 6-7 Summary of each model selected by stepwise regression analysis

Model	Variable	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	Shear	0.391	0.153	0.145	1.27076
2	Compression	0.523	0.274	0.259	1.18246
3	Bending	0.593	0.352	0.332	1.12262
4	Tensile	0.629	0.395	0.371	1.08983

The first model has the fabric mechanical block N3 (Shear) in the regression equation, with R^2 of 0.145. The second model with both block N3 (Shear) and N4 (compression) in the regression equation gives an R^2 of 0.259. However, these four fabric blocks (N3, N4, N2 and N1) could not even explain 50% of the hand value smoothness in this regression analysis.

The primary hand value of smoothness is an expression of smooth, limber and soft feeling. Fabric shear property is affected by yarn friction and fabric weave, thus affecting the fabric smoothness. Therefore, the primary hand value of smoothness is correlated with fabric mechanical block (N3) shear.

The next fabric mechanical block also contributing significantly to smoothness is N4, fabric compression properties. A bulky soft fabric with a high degree of compressibility would contribute to the feeling of fabric smoothness or sleekness.

But these four fabric mechanical blocks (N3, N4, N2 and N1) combine together to explain less than 0.4 of variance for the primary hand value of smoothness in the warp knitted fabrics. The important blocks of N5 Surface is not correlated to fabric smoothness since its significant level is >0.05. Fabric smoothness can be influenced by fabric surface properties. A smooth, soft fabric surface increases the feelings of fabric smoothness or sleekness. A rough and coarse surface would reduce this feeling. As there is less than 50% correlation to fabric smoothness, no significant finding is pointed out.

6.3.3 Fabric Softness to KES-F Mechanical Blocks

Table 6-8 Correlation matrix between mechanical blocks and softness

	N1	N2	N3	N4	N5	Softness
N1	1					
N2	*-0.214	1				
N3	**-0.418	**0.614	1			
N4	0.139	**0.472	*0.24	1		
N5	-0.074	0.062	*-0.196	-0.018	1	
Softness	0.049	0.007	-0.091	**0.522	0.004	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Table 6-9 Stepwise regression analysis for softness hand value

Model	**Variables Entered**	**Method**
1	Compression (N4)	Stepwise (Criteria: Probability-of-F-to-enter ≤ 0.05, Probability-of-F-to-remove ≥.100).
2	Bending (N2)	Stepwise (Criteria: Probability-of-F-to-enter ≤ 0.05, Probability-of-F-to-remove ≥.100).

The first block entered in to the regression equation is N4 (compression); followed by N2 (bending).

Table 6-10 Summary of each model selected by stepwise regression analysis

Model	Variable	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	Compression	0.552	0.305	0.298	1.21906
4	Bending	0.623	0.388	0.376	1.14971

Table 6-8 and Table 6-9 show the correlation matrix and stepwise regression analysis of softness respectively. Table 6-10 shows the power of explanation (R^2) for two models in the regression equation. The first model has mechanical block N4 (compression), with R^2=0.298. The second model has mechanical block N4 (compression) and N2 (bending) in the regression equation, with R^2=0.376. Again, two fabric mechanical blocks (N4 and N2) are insufficient to explain the hand value of softness in this regression analysis since the R^2value is less than 0.4.

The definition of softness relates to the feeling arising from a bulky, rich and well-formed sensation. This kind of bulk feeling is directly related to fabric compressibility and therefore, it shows a strong correlation with fabric compression properties (N4). Fabric thickness is also an important attribute to explain the fabric softness.

Although fabric softness is somehow affected by compression property, the small correlation cannot represent the KES-F mechanical properties as a whole.

6.4 Stepwise Regression Analysis on Primary Hand Values to Total Hand Value

The primary hand values of smoothness, stiffness and fullness/softness are considered here as independent variables and the Total Hand Value (THV) is used here as the dependent variable for this multiple regression analysis. The results of the stepwise regression analysis are shown in Table 6-11.

Correlation matrix between primary hand value and total hand value is shown in Chapter 5, Table 5-1.

Table 6-11 Stepwise regression analysis for total hand value

Model	**Variables Entered**	**Method**
1	Softness	Stepwise (Criteria: Probability-of-F-to-enter ≤ 0.05, Probability-of-F-to-remove ≥.100).
2	Stiffness	Stepwise (Criteria: Probability-of-F-to-enter ≤ 0.05, Probability-of-F-to-remove ≥.100).
3	Smoothness	Stepwise (Criteria: Probability-of-F-to-enter ≤ 0.05, Probability-of-F-to-remove ≥.100).
4	Soft feeling	Stepwise (Criteria: Probability-of-F-to-enter ≤ 0.05, Probability-of-F-to-remove ≥.100).

Table 6-12 Summary of each model selected by stepwise regression analysis

Model	Variable	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	Softness	0.907	0.823	0.822	0.28203
2	Stiffness	0.918	0.843	0.84	0.26697
3	Smoothness	0.970	0.94	0.938	0.16597
4	Soft feeling	0.975	0.95	0.948	0.15237

Table 6-12 presents the summary of each model selected by stepwise regression analysis. The first model in the regression equation has one primary hand value of softness with the R^2 of 0.822. The second model of the regression equation has two hand values of softness and stiffness with R^2 of 0.84. The third model with three primary hand values in the regression equation gives R^2 of 0.938. The last model with all four primary hand values in the regression equation gives R^2 of 0.948, very close to 1.

The primary hand value softness accounts for over 80% of the total hand value in the regression equation. This result means that softness represents the prime factor contributing to total hand value for these warp knitted fabrics. The hand value of softness is controlled by fabric mechanical Block B4 (compression) and B2 (bending).

6.5 Summary

In this chapter, the relationship of each fabric mechanical property obtained from the KES-F instruments to the fabric primary hand values is examined by means of stepwise multiple linear regression analysis of variances (ANOVA). This technique can identify the most significant fabric mechanical property in the regression equation to explain the fabric hand values for 105 warp knitted fabric samples.

Interesting outcomes were found by applying mechanical blocks to regression model. Stiffness property was indicated to be affected by shear, bending and surface attributes. Smoothness was influenced by shear, bending, compression and tensile properties. Softness was only impacted by compression and bending behavior of warp knitted fabrics.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Having a sample size of 105 warp knitted fabrics, the data set was large enough for ideal evaluation of the mechanical properties and physical properties by objective measurements. Using a traditional fabric hand evaluation of KES-F system and a new approach of fabric hand measurement by PhabrOmeter system, different fabric attributes can be obtained from the system in terms of stiffness, softness and smoothness, which provide quantitative methods to measure fabric hands objectively.

Objective measurement and subjective assessment to quantitatively describe fabric hand properties of fabrics samples are always the mainstream in the study of fabric hand. By combining different instrumentations that used to measure various warp knitted fabrics, distinct measurement methods were developed on the basis of different measurement principles.

This project investigates the correlation between fabric hand properties under mechanical and physical principles and objectives are achieved as follows:

1. Based on the fabric mechanical properties measurement, it was found that fabric thickness and weight per unit area were positively associated with mechanical parameters. The behavior of warp knitted fabrics exhibits effects on tensile, shear, bending, compression and surface results obtained by KES-F system.

2. For the fabric thickness and weight assessment, results revealed that physical variables were significantly correlated with KES-F measurement. Fabric primary hand values and total hand value of sample fabrics were thus affected by fabric thickness and weight consequently. In term of fabric hand, the value of stiffness, smoothness and softness assumed to be ascertained from fabric objective measurement (FOM) and subjective assessment. Fabrics with various specifications were observed and significant results were found by these measurement.

3. PhabrOmeter system was used as an alternative approach to measure fabric hand. Correlation between physical properties and hand values were inquired in spite of homogeneous hand results. By separating linear density group, the significances of each fabric weight group were relatively weaker than that of KES-F and subjective measurement.

4. Notwithstanding being ancient and intuitive, subjective assessment on fabric hand contributed to meaningful first-hand findings from real person. By setting same descriptors of hand attributes with KES-F and PhabrOmeter system, close relationships towards fabric properties and evaluation methods were achieved.

5. Multiple regression model ANOVA was used to analyze the affiliation of mechanical variables and fabric hand values. Influencing factors like shear, bending and compression behavior compliance with the functions of warp knitted fabrics. That explained the strong R^2 value towards fabric stiffness, smoothness, softness and total hand properties.

7.2 Recommendations

The objectives of the research project have been achieved. In order to further improve and manipulate the fabric hand observation, some future works are recommended with details as follows.

1. In this research, the sample size has direct impact on data analysis. As 105 types of warp knitted fabrics were derivative on higher chance of uncertainty and variability, the accuracy of the results of correlation and comparative studies could be affected. To develop a deeper and profound analysis, reduce in sample types will help.

2. Scarcity of fabric specifications such as missing information of yarn count and yarn types narrows the pluralism of data analysis. Although fabric thickness and weight provide enough inference for fabric hand attributes, more structural details on warp knitted fabrics may give a better understanding on its hand characteristics.

3. The number of guide bars, the gauge length, and the lapping movement of warp knitting machines determine the construction of warp knitted fabrics. Collecting more machinery information is recommended to enhance the understanding in the relationship of structural property and mechanical parameters.

4. Warp knitted fabrics is unique in structure due to its porosity feature and the variability of possible designs. Further analysis on pattern construction of warp knitted fabrics is necessary due to the influence of knitting structure (Bensaid et al., 2006). Measuring fabric tightness and cover factor will consolidate the simulation of elasticity function so as to obtain significant in tensile and shear properties.

5. The model for predicting the hand properties of warp knitted fabrics from mechanical and physical properties will be generated by developing empirical formula. This objective hand evaluation method is essential to establish the ground for the control of warp knitted fabric properties. The parameters explaining the hand properties are selected using Kawabata's mechanical and physical parameters through statistical analysis, for eliminating overlapped elements, which show collinearity.

6. Type of fiber is an important factor at hand properties. Polyester is mostly used in this study. However, some types contain bamboo, nylon and polypropylene. Evaluation of fabrics containing different fibers may cause different results and deviations. In further studies, effect of fiber type as another parameter on fabric hand can be also investigated.

7. The effect of background information of judges such as age, gender, education, nationality etc. on accuracy of hand properties determination in subjective measurement can be examined comparatively and evaluated versus objective test methods.

8. This study has useful scientific information. Findings supported by further investigation can be proposed to solve problems of industrial production and to enhance hand properties of knitted fabrics. Further study can be arranged on the basis of problems and expectations of a knitting mill. Consequently, scientific information can be transferred into industrial mass production.

Appendix 1 Summary Table for the Warp Knitted Fabric Specifications

Fabric Specifications								
Sample	Article No.	Construction	Colour	Weight (g/m^2)	Thickness (mm)	Fibre Content	Yarn Type	Yarn Count
1	DL8065	Mesh	Deep Blue	65	0.45	Polyester	N/A	75D/72F
2	DL8085	Mesh	White	85	0.44	Polyester	N/A	75D/72F
3	DL8110	Mesh	White	110	0.57	Polyester	N/A	75D/72F
4	ZT-0426-65	Mesh	Grey	65	0.36	67/34 Polyester/Bamboo Charcoal	N/A	68D/24F
5	ZT-0610-60	Mesh	Grey	60	0.34	67/34 Polyester/Bamboo Charcoal	N/A	75D/36F
6	0426-60	Mesh	Deep Blue	60	0.26	Polyester	FDY	50D/24F
7	0426-65	Mesh	Grey	65	0.31	Polyester	FDY	68D/24F
8	0426B-65	Mesh	Black	65	0.29	Polyester	FDY	50D/24F
9	0610B-60	Mesh	Black	60	0.25	Polyester	FDY	75D/36F
10	0610-65 (W)	Mesh	White	65	0.41	Polyester	DTY	75D/36F
11	0610-65	Mesh	Black	65	0.43	Polyester	DTY	75D/36F
12	0610-70	Mesh	Grey	70	0.47	Polyester	DTY	75D/36F
13	0616-80	Mesh	Black	80	0.25	Polyester	FDY	50D/24F
14	0616-110	Mesh	Black	110	0.35	Polyester	FDY	68D/24F
15	0616-130	Mesh	Black	130	0.38	Polyester	FDY/G	75D/36F
16	0715-110	Mesh	Green	110	0.62	Polyester	DTY	75D/36F
17	0716-100	Mesh	Black	100	0.31	Polyester	FDY	68D/24F
18	0716-105	Mesh	Grey	105	0.34	Polyester	FDY	68D/25F
19	0716-110	Mesh	Black	110	0.47	Polyester	FDY	68D/26F
20	0716-110L	Mesh	Black	110	0.56	Polyester	DTY	75D/36F
21	0716-120L	Mesh	Black	120	0.56	Polyester	DTY	75D/36F
22	0718-100	Mesh	White	100	0.34	Polyester	N/A	N/A
23	0810-60	Mesh	Black	60	0.45	Polyester	N/A	N/A
24	0913-120	Mesh	Deep Blue	120	0.48	Polyester	FDY	100D/36F
25	3215-130	Mesh	Black	130	0.45	Polyester	N/A	75D/36F
26	3216W-100	Mesh	Dark Grey	100	0.52	Polyester	DTY	75D/36F
27	3226-115	Mesh	Black	115	0.42	Polyester	DTY*FDY	75D/36*50D/24F
28	3728-85	Mesh	Orange-red	85	0.57	Polyester	DTY	75D/36F
29	K055-55	Mesh	Grey	55	0.41	Polyester	DTY	75D/36F
30	NL0426-55	Mesh	Dark Grey	55	0.28	Nylon	FDY	NL40D/24F
31	K082-200	3D Mesh	Black	200	0.45	Polyester	FDY/G*FDY	75D/36F*75D/36F
32	T112-180	Space Mesh	Black	180	1.45	Polyester	FDY	75D
33	T112-210	Space Mesh	Black	210	2.26	Polyester	FDY	75D
34	T140-250	Space Mesh	Black	250	1.84	Polyester	FDY	150D
35	0426B-100G	Shiny Mesh	Light Grey	100	0.33	Polyester	FDY/G	75D/36F
36	0610-75G (G)	Shiny Mesh	Grey	75	0.32	Polyester	FDY/G	75D/36F
37	0610-75G	Shiny Mesh	Blue	75	0.28	Polyester	FDY/G	75D/36F
38	0716-110G	Shiny Mesh	Grey	110	0.36	Polyester	FDY/G	75D/37F
39	0012-120	Brushed Mesh	White	120	0.51	Polyester	DTY*FDY	75D/36F*50D/24F
40	0012-130	Brushed Mesh	Black	130	0.61	Polyester	DTY*FDY	75D/36F*50D/24F
41	0516-145	Brushed Mesh	Black	145	0.67	Polyester	DTY*FDY	75D/36F*50D/24F
42	0715-120BR	Brushed Mesh	Black	120	0.64	Polyester	DTY	75D/36F
43	3214-160	Brushed Mesh	Black	160	0.78	Polyester	DTY*FDY	75D/36F*50D/24F
44	3715-160	Brushed Mesh	Light Grey	160	0.69	Polyester	DTY*FDY	75D/36F*50D/24F
45	3912-130	Brushed Mesh	Blue-grey	130	0.61	Polyester	DTY*FDY	75D/36F*50D/24F
46	3732-190	3D Brushed Mesh	White	190	0.93	Polyester	N/A	50D/24F*75D/36F
47	3012-110	Tricot	Black	110	0.29	Polyester	FDY	50D/72F
48	0414-100	Brushed Tricot	Dark Grey	100	0.4	Polyester	FDY	50D/24F
49	0414-160	Brushed Tricot	Black	160	0.95	Polyester	FDY	68D/24F
50	J0414-260	Brushed Tricot	Black	260	0.67	Polyester	FDY	75D/36F
51	Y0414-120	Brushed Tricot	Orange	120	0.61	Polyester	FDY	50D/24F
52	Y0414-160	Brushed Tricot	White	160	0.68	Polyester	FDY	68D/24F

53	Y0414-200 (G)	Brushed Tricot	Grey	200	0.67	Polyester	FDY	75D/36F
54	Y0414-200	Brushed Tricot	Beige	200	0.57	Polyester	FDY	75D/36F
55	3617-125 (P)	Micro Brushed Tricot	Pink	125	0.52	Polyester	DTY	50D/72F
56	3617-125	Micro Brushed Tricot	Grey	125	0.57	Polyester	DTY	50D/73F
57	3617-140	Micro Brushed Tricot	Grey	140	0.64	Polyester	DTY	50D/74F
58	00101-10824-120	Bird Eye Mesh	Grey	120	0.6	62/38 Poly/Polypropylene	N/A	75D/72F(S)+52D/72PP
59	0716-120L	Mesh	Dark Orange	120	0.56	Polyester	DTY	75D/36F
60	0716-110G	Shiny Mesh	Sliver	110	0.37	Polyester	FDY/G	75D/37F
61	3171-75	Brushed Mesh	Deep Blue	75	0.38	Polyester	DTY*FDY	N/A
62	3171-125	Brushed Mesh	Deep Blue	125	0.57	Polyester	DTY*FDY	N/A
63	3172-75	Brushed Mesh	Yellow	75	0.43	Polyester	DTY*FDY	N/A
64	3172-125	Brushed Mesh	Yellow	125	0.61	Polyester	DTY*FDY	N/A
65	3173-125	Brushed Mesh	Dark Grey	125	0.55	Polyester	DTY*FDY	N/A
66	4286-75	Brushed Mesh	Dark Grey	75	0.4	Polyester	DTY*FDY	N/A
67	3173-75	Brushed Mesh	Purple	75	0.4	Polyester	DTY*FDY	N/A
68	3178-75	Brushed Mesh	Light Green	75	0.35	Polyester	DTY*FDY	N/A
69	3179-75	Brushed Mesh	Blue	75	0.36	Polyester	DTY*FDY	N/A
70	3175-160	Brushed Mesh	Red	160	0.77	Polyester	DTY*FDY	75D/36F*50D/24F
71	DL3173N-75	Brushed Mesh	Red	75	0.45	Polyester	DTY*FDY-DL	50D/48F*30D/24F
72	DL3173N-125	Brushed Mesh	Red	125	0.65	Polyester	DTY*FDY-DL	50D/48F*30D/24F
73	3171-125	Brushed Mesh	Green	125	0.6	Polyester	DTY*FDY	N/A
74	3172-125	Brushed Mesh	Red	125	0.6	Polyester	DTY*FDY	N/A
75	3173-125	Brushed Mesh	Pink	125	0.7	Polyester	DTY*FDY	N/A
76	0610-65	Mesh	Black	65	0.42	Polyester	DTY	75D/36F
77	0716-120L	Mesh	Black	120	0.55	Polyester	DTY	75D/36F
78	0610-45	Ultra Micro Mesh	Blue	45	0.33	Polyester	N/A	N/A
79	0716-75L	Ultra Micro Mesh	Light Blue	75	0.41	Polyester	N/A	N/A
80	TX4292-85	Brushed Mesh	Light Blue	85	0.49	Polyester	DTY*FDY-DL	50D/48F*30D/24F
81	TX4293-80	Brushed Mesh	Blue	80	0.48	Polyester	DTY*FDY-DL	50D/48F*30D/24F
82	TX4294-75	Brushed Mesh	Grass-green	75	0.45	Polyester	DTY*FDY-DL	50D/48F*30D/24F
83	TX4295-80	Brushed Mesh	Deep Blue	80	0.5	Polyester	DTY*FDY-DL	50D/48F*30D/24F
84	DL3171-75	Brushed Mesh	Green	75	0.39	Polyester	DTY*FDY-DL	50D/48F*30D/24F
85	DL3171-125	Brushed Mesh	Blue	125	0.55	Polyester	DTY*FDY-DL	50D/48F*30D/24F
86	DL3172-75	Brushed Mesh	Cherry-red	75	0.47	Polyester	DTY*FDY-DL	50D/48F*30D/24F
87	DL3173N-75	Brushed Mesh	Grey	75	0.41	Polyester	DTY*FDY-DL	50D/48F*30D/24F
88	DL3173N-125	Brushed Mesh	Deep Blue	125	0.54	Polyester	DTY*FDY-DL	50D/48F*30D/24F
89	DL3173W-75	Brushed Mesh	Dark Berry	75	0.43	Polyester	DTY*FDY-DL	50D/48F*30D/24F
90	DL3178-75	Mesh	Blue	75	0.39	Polyester	N/A	N/A
91	DL3179-75	Mesh	Orange	75	0.4	Polyester	N/A	N/A
92	2103C-130	Mesh	Grey	130	0.38	Polyester	N/A	N/A
93	2105-65	Mesh	Flame Orange	65	0.4	Polyester	N/A	N/A
94	2604-130	Brushed Mesh	Navy	130	0.67	Polyester	N/A	N/A
95	2806-110	Brushed Tricot	Dark Berry	110	0.45	Polyester	N/A	N/A
96	9303-035	Brushed Tricot	Ecehing Blue	100	0.61	Polyester	N/A	N/A
97	9315-50	Mesh	Princess Blue	50	0.35	Polyester	N/A	N/A
98	9509-45	Mesh	Moccancian Blue	45	0.24	Polyester	N/A	N/A
99	9604-70	Mesh	Pink Glow	70	0.38	Polyester	N/A	N/A
100	9605-75	Mesh	Blue Granite	75	0.41	Polyester	N/A	N/A
101	9710-75	Mesh	Air Blue	75	0.47	Polyester	N/A	N/A
102	9901-80	Brushed Mesh	Alloy	80	0.52	Polyester	N/A	N/A
103	FL907-140	Space Mesh	Black	140	1.56	Polyester	N/A	N/A
104	K055-45	Ultra Micro Mesh	Earth	45	0.28	Polyester	N/A	N/A
105	DL9605-110	Mesh	Light Blue	110	0.59	Polyester	N/A	N/A

Appendix 2 Summary Table for the KES-FB Test Results

KES Value		Tensile				Bending		Shearing			Surface			Compression		
Sample	Article No.	EMT (%)	LT (-)	WT (gf/cm2)	RT (%)	B-MEAN (gf*cm2/cm)	2HB-MEAN (gf*cm/cm)	G-MEAN	2HG-MEAN	2HG5-MEAN	MIU	MMD	SMD	LC	WC (gf/cm2)	RC (%)
1	DL8065	13.88	0.6275	2.17	53.05	0.007	0.0086	1.25	4.73	4.54	0.351	0.01805	4.94	0.54	0.292	49.03
2	DL8085	7.765	0.7915	1.54	53.975	0.008	0.00755	1.865	5.355	5.195	0.247	0.0209	6.01	0.529	0.231	50
3	DL8110	8.12	0.791	1.61	48.995	0.0155	0.01585	1.565	4.9	4.995	0.2935	0.02285	6.685	0.518	0.248	46.18
4	ZT-0426-65	5.225	0.7335	0.97	53.27	0.0125	0.006	1.26	2.725	2.825	0.232	0.02625	8.16	0.486	0.203	52.29
5	ZT-0610-60	4.35	0.7315	0.81	49.845	0.0095	0.0092	2.605	7.085	4.3	0.234	0.02835	6.59	0.507	0.218	51.3
6	0426-60	3.84	0.6445	0.655	51.955	0.0125	0.00635	1.585	3.74	3.86	0.223	0.02715	7.62	0.564	0.0112	36.21
7	0426-65	3.485	0.717	0.625	44.77	0.02	0.0099	1.83	4.115	4.07	0.2195	0.029	8.795	0.526	0.143	40.31
8	0426B-65	5.335	0.6815	0.945	43.91	0.0105	0.006	1.685	4.945	4.87	0.2435	0.02535	6.66	0.466	0.13	39.07
9	0610B-60	2.225	0.6915	0.39	57.525	0.011	0.002	2.42	8.545	4.505	0.22	0.03465	8.365	0.532	0.139	33.41
10	0610-65 (W)	11.215	0.397	4.01	52.84	0.009	0.0101	1.75	3.68	3.42	0.205	0.0112	6.46	0.532	0.283	56.83
11	0610-65	9.08	0.402	3.21	55.29	0.011	0.0093	1.7	3.59	3.3	0.211	0.0133	7.26	0.541	0.252	54.57
12	0610-70	12.1	0.694	2.1	64.51	0.011	0.00885	1.435	2.855	2.905	0.2215	0.0286	4.22	0.538	0.274	53.11
13	0616-80	4.98	0.6	0.8	58.85	0.0085	0.0063	1.49	2.78	2.405	0.19	0.0215	7.455	0.523	0.122	44.66
14	0616-110	7.57	0.633	1.27	58.405	0.013	0.0045	1.14	2.435	2.37	0.1975	0.01935	5.225	0.545	0.175	43.53
15	0616-130	2.87	0.5895	0.425	52.525	0.021	0.01305	2.335	5.455	5.685	0.188	0.022	5.345	0.494	0.116	43.84
16	0715-110	11.63	0.722	2.135	51.56	0.0195	0.01675	1.135	3.275	3.445	0.239	0.01955	7.135	0.51	0.267	47.19
17	0716-100	2.615	0.69	0.46	45.975	0.0205	0.0105	2.39	6.74	6.535	0.145	0.03505	5.115	0.538	0.128	38.65
18	0716-105	6.43	0.649	1.075	53.17	0.0085	0.0046	1.195	4.1	4.085	0.2055	0.02425	5.72	0.521	0.161	44.92
19	0716-110	5.58	0.618	0.895	57.06	0.0175	0.0124	1.845	3.745	3.98	0.2	0.0173	5.335	0.513	0.2	52
20	0716-110L	14.015	0.7405	2.63	63.665	0.0125	0.014	1.06	2.45	2.46	0.2955	0.0219	4.4	0.531	0.281	48.64
21	0716-120L	9.89	0.8355	2.09	59.94	0.017	0.01345	1.365	3.105	3.26	0.2305	0.02255	4.75	0.522	0.245	49.69
22	0718-100	1.715	0.6935	0.3	60.76	0.032	0.0093	2.385	6.095	6.635	0.1645	0.0239	6.375	0.598	0.083	45.16
23	0810-60	17.415	0.719	3.175	60.315	0.007	0.0095	1.33	3.315	3.12	0.221	0.02045	5.005	0.551	0.298	50.06
24	0913-120	3.045	0.6615	0.51	38.305	0.034	0.0325	2.305	7.34	5.585	0.2295	0.0267	7.33	0.524	0.499	42.29
25	3215-130	6.305	0.76	1.225	56.045	0.0225	0.01045	2.225	4.56	4.935	0.206	0.0314	5.35	0.494	0.157	48.95
26	3216W-100	5.6	0.7095	1	51.67	0.018	0.01405	1.84	5.49	5.13	0.2395	0.0239	5.525	0.5	0.234	48.5
27	3226-115	4.375	0.6975	0.76	50.73	0.023	0.01185	1.93	5.5	5.875	0.222	0.02305	5.51	0.49	0.167	44.74
28	3728-85	9.22	0.8055	1.885	59.62	0.0165	0.0094	1.085	1.92	2.22	0.2525	0.022	10.925	0.553	0.288	51.7
29	K055-55	11.95	0.382	5.53	48.13	0.009	0.0081	1.25	4.18	3.9	0.185	0.0147	7.34	0.547	0.202	48.92
30	NL0426-55	6.67	0.758	1.29	43.165	0.0055	0.0039	1.3	4.785	4.965	0.205	0.02305	6.165	0.502	0.151	35.54
31	K082-200	1.255	1.081	0.28	71.175	0.16	0.1109	2.78	4.825	8.89	0.185	0.0238	3.485	0.443	0.183	38.38
32	T112-180	4.31	0.701	0.75	41.71	0.5715	0.531	2.53	7.88	9.905	0.218	0.0306	6.82	0.696	0.446	62.78
33	T112-210	3.395	0.7515	0.635	43.325	1.459	2.0759	4.79	12.705	18.74	0.235	0.03335	8.03	0.873	0.946	69.03
34	T140-250	2.045	0.684	0.35	52.74	1.052	1.342	3.66	8.85	11.285	0.252	0.0292	7.945	0.723	0.637	66.11
35	0426B-100G	5.295	0.5835	0.83	51.495	0.0125	0.00675	1.965	3.97	4.04	0.21	0.02265	6.175	0.498	0.116	41.23
36	0610-75G (G)	2.355	0.618	0.365	54.345	0.016	0.01535	2.65	7.29	2.33	0.2315	0.0299	9.595	0.644	0.141	41.83
37	0610-75G	1.45	0.6	0.215	55.665	0.02	0.0142	4.645	17.015	3.3	0.2125	0.033	8.225	0.601	0.102	38.74
38	0716-110G	3.655	0.733	0.685	48.63	0.017	0.0071	1.95	6.065	5.8	0.2335	0.02675	4.245	0.454	0.146	41.54
39	0012-120	2.475	0.54	0.335	52.905	0.0275	0.02425	2.98	5.905	3.455	0.208	0.03055	3.61	0.516	0.674	52.43
40	0012-130	2.75	0.5115	0.35	56.76	0.03	0.02955	3.655	4.64	2.32	0.1985	0.0362	4.325	0.501	0.526	48.7
41	0516-145	2.505	0.641	0.4	52.31	0.05	0.3066	3.185	5.275	4.515	0.1895	0.02105	4.915	0.537	0.632	51.68
42	0715-120BR	7.605	0.743	1.505	56.17	0.016	0.01805	1.575	3.63	3.75	0.2525	0.0208	5.2	0.502	0.574	48.67
43	3214-160	2.735	0.4975	0.345	59.835	0.0385	0.03095	3.365	5.59	5.74	0.213	0.02625	3.525	0.487	0.781	57.22
44	3715-160	2.25	0.692	0.385	59.585	0.0355	0.0304	3.565	5.165	3.745	0.21	0.0215	5.905	0.512	0.599	50.39
45	3912-130	2.48	0.39195	0.455	58.695	0.023	0.02055	2.635	5.42	5.295	0.2205	0.02285	4.2	0.528	0.658	53.83
46	3732-190	4	0.613	0.595	54.875	0.1235	0.13255	4.055	6.28	6.8	0.212	0.0288	4.895	0.438	1.029	47.87
47	3012-110	4.625	0.777	0.905	49.375	0.0105	0.00465	1.645	5.12	5.38	0.159	0.0174	4.395	0.36	0.078	38.61
48	0414-100	2.315	0.519	0.3	55.705	0.0145	0.0202	3.66	14.815	7.24	0.206	0.01945	3.19	0.425	0.698	57.22
49	0414-160	1.945	0.4285	0.205	66.36	0.0505	0.04165	5.195	13.54	8.26	0.2265	0.025	3.325	0.641	1.067	59.97
50	J0414-260	1.575	0.5925	0.225	60.43	0.092	0.0652	3.66	4.765	5.37	0.1825	0.03265	2.01	0.513	0.377	50.18
51	Y0414-120	5.24	0.703	0.92	42.735	0.0155	0.0172	1.315	4.695	4.175	0.2125	0.01985	2.74	0.546	0.666	53.25
52	Y0414-160	3.195	0.4995	0.395	51.52	0.0265	0.02675	1.965	4.315	4.315	0.1845	0.01985	2.24	0.493	0.583	57.34

53	Y0414-200 (G)	2.15	0.5215	0.28	50.345	0.0405	0.04015	3.12	5	6.95	0.17	0.02155	2.51	0.499	0.387	59.82
54	Y0414-200	1.535	0.5135	0.2	61.39	0.0695	0.0463	4.08	5.065	6.345	0.1785	0.02035	2.76	0.444	0.324	60.83
55	3617-125 (P)	3.76	0.7185	0.69	52.25	0.0155	0.0177	2.215	5.115	5.79	0.208	0.02685	2.83	0.506	0.407	42.22
56	3617-125	3.255	0.724	0.59	53.095	0.0185	0.02475	2.255	4.995	5.81	0.213	0.021	2.81	0.513	0.477	44.37
57	3617-140	3.95	0.6925	0.685	52.205	0.017	0.02285	2.29	5.395	5.875	0.2215	0.01745	2.33	0.476	0.369	45.18
58	00101-10824-120	20.815	0.7575	4.01	44.225	0.0075	0.0089	0.57	1.925	1.86	0.226	0.0172	4.61	0.503	0.241	43.37
59	0716-120L	12.56	0.689	2.21	70.08	0.012	0.0143	1.03	1.9	1.92	0.243	0.0184	8.72	0.53	0.32	57.72
60	0716-110G	3.76	0.72	0.7	47.41	0.015	0.011	1.72	5.55	5.28	0.207	0.0121	6.34	0.554	0.155	46.67
61	3171-75	2.89	0.649	0.47	48.46	0.01	0.0098	2.07	6.64	5.56	0.238	0.008	6.1	0.485	0.355	51.08
62	3171-125	4.96	0.645	0.8	51.13	0.014	0.0164	1.79	5.08	5.24	0.256	0.0096	6.09	0.504	0.459	51.16
63	3172-75	3.26	0.595	0.49	50.9	0.01	0.0116	2.05	6.35	5.67	0.247	0.0135	12.62	0.459	0.298	49.27
64	3172-125	6.5	0.678	1.1	48.89	0.015	0.0152	1.68	4.55	4.91	0.248	0.0111	10.22	0.473	0.413	51.07
65	3173-125	4.93	0.654	0.82	51.73	0.012	0.0142	1.76	4.79	5.07	0.228	0.0128	7.57	0.462	0.313	50.86
66	4286-75	3.64	0.632	0.58	49.34	0.011	0.0089	1.76	5.55	5.18	0.239	0.0086	8.6	0.496	0.304	49.94
67	3173-75	2.62	0.615	0.4	49.5	0.012	0.0131	2.28	6.36	5.26	0.237	0.013	8.13	0.452	0.338	47.24
68	3178-75	2.81	0.618	0.43	47.84	0.014	0.0124	1.64	4.44	4.51	0.231	0.0078	6.43	0.461	0.268	48.45
69	3179-75	2.93	0.605	0.45	47.93	0.011	0.0164	1.49	4.02	4.15	0.223	0.011	6.85	0.439	0.269	49.26
70	3175-160	2.62	0.614	0.4	50.02	0.034	0.0502	3.98	6.88	3.98	0.278	0.01	5.76	0.515	0.561	49.32
71	DL3173N-75	6.32	0.649	1.04	54.77	0.008	0.0088	1.32	3.33	3.49	0.225	0.0103	9.01	0.486	0.304	53.94
72	DL3173N-125	9.13	0.717	1.64	52.66	0.01	0.0147	1.2	3.59	3.76	0.257	0.009	6.24	0.491	0.496	49.28
73	3171-125	3.99	0.634	0.63	47.19	0.015	0.0191	2.13	5.78	5.58	0.28	0.0126	6.5	0.487	0.506	43.48
74	3172-125	5.57	0.596	0.83	48.47	0.014	0.0126	1.91	5.13	5.02	0.273	0.0115	10.47	0.458	0.456	43.79
75	3173-125	3.89	0.637	0.62	48.94	0.014	0.0228	2.18	5.8	5.66	0.285	0.0103	7.15	0.529	0.663	47.68
76	0610-65	9.88	0.683	1.69	71.78	0.005	0.0049	1.62	2.24	2.39	0.197	0.0102	7.11	0.536	0.268	57.09
77	0716-120L	8.81	0.734	1.64	56.11	0.016	0.0152	1.39	3.25	3.43	0.203	0.0115	8.27	0.507	0.221	50.98
78	0610-45	8.84	0.709	1.58	47.17	0.005	0.0046	1.63	6.14	5.39	0.229	0.0086	7.61	0.531	0.291	48.86
79	0716-75L	9.8	0.65	1.64	44.13	0.006	0.0077	1	4.03	3.66	0.259	0.0098	7.91	0.537	0.31	48.12
80	TX4292-85	6.04	0.693	1.06	52.79	0.01	0.0093	1.43	5.78	5.63	0.226	0.007	5.46	0.519	0.24	49.3
81	TX4293-80	3.41	0.703	0.6	54.63	0.01	0.0096	1.93	6.64	6.18	0.229	0.0103	10.46	0.513	0.223	51.72
82	TX4294-75	2.93	0.738	0.55	57	0.014	0.0109	2.02	6.61	5.64	0.197	0.0099	6.33	0.519	0.209	53.25
83	TX4295-80	3.64	0.716	0.66	52.22	0.011	0.0075	1.78	6.38	5.76	0.202	0.009	7.58	0.523	0.224	52.46
84	DL3171-75	4.09	0.666	0.68	54.2	0.009	0.0108	1.71	4.07	4.03	0.202	0.0208	6.72	0.43	0.299	52.96
85	DL3171-125	6	0.726	1.09	52.14	0.015	0.0135	1.46	3.61	4.01	0.217	0.0085	6.2	0.518	0.441	49.63
86	DL3172-75	5.03	0.65	0.81	53.64	0.007	0.0084	1.55	3.99	4.11	0.214	0.0095	11.89	0.429	0.295	53.27
87	DL3173N-75	6.12	0.659	1.01	53.69	0.008	0.0097	1.37	3.53	3.74	0.195	0.012	9.37	0.43	0.292	53.6
88	DL3173N-125	6.44	0.666	1.07	54.12	0.016	0.0161	1.45	3.48	3.86	0.21	0.009	8.06	0.419	0.339	51.32
89	DL3173W-75	6.2	0.68	1.06	52.78	0.01	0.0112	1.38	3.63	3.84	0.184	0.0092	6.55	0.443	0.265	54.18
90	DL3178-75	3.63	0.633	0.58	54.76	0.011	0.0108	1.55	3.55	3.62	0.173	0.0083	11.48	0.428	0.248	53.17
91	DL3179-75	3.6	0.727	0.67	58.14	0.014	0.0116	1.55	3.03	3.21	0.181	0.0095	8.73	0.435	0.261	52.93
92	2103C-130	2.6	0.58	0.39	60.28	0.025	0.0186	2.7	5.6	5.47	0.28	0.0097	7.59	0.469	0.131	42.55
93	2105-65	9.78	0.721	1.78	52.33	0.006	0.0064	0.9	2.72	2.61	0.281	0.012	8.73	0.534	0.269	54.08
94	2604-130	2.37	0.63	0.37	56.49	0.024	0.0279	3.33	6.21	3.82	0.286	0.0063	5.5	0.478	0.488	47.62
95	2806-110	10.77	0.315	0.84	43.66	0.012	0.0167	1.36	5.94	4.52	0.237	0.0133	7	0.471	0.494	45.29
96	9303-035	10.99	0.326	0.9	56.81	0.014	0.0171	1.97	8.16	5.28	0.265	0.0103	3.45	0.591	1.417	53.18
97	9315-50	5.71	0.733	1.08	51.79	0.006	0.0019	0.9	2.39	2.25	0.161	0.01	9.2	0.496	0.137	42.67
98	9509-45	10.91	0.73	2.01	51.18	0.004	0.0049	1.41	5.07	4.84	0.214	0.0081	6.13	0.541	0.262	52.34
99	9604-70	11.04	0.715	2.05	45.18	0.01	0.0055	0.87	3	2.71	0.215	0.0079	9.45	0.517	0.23	50.22
100	9605-75	9.48	0.715	1.72	48.1	0.004	0.0059	1	3.85	3.57	0.22	0.0108	7.48	0.523	0.268	52.62
101	9710-75	14.27	0.718	2.57	47.12	0.005	0.0076	0.82	2.97	2.69	0.218	0.01	8.03	0.511	0.266	51.2
102	9901-80	5.22	0.644	0.84	50	0.007	0.0071	1.43	3.93	3.95	0.243	0.0055	4.93	0.499	0.595	49.41
103	FL907-140	5.27	0.789	1.03	49.44	0.302	0.3151	1.76	6.54	6.85	0.173	0.0195	7.78	0.807	0.705	73.58
104	K055-45	16.6	0.372	4.69	44.14	0.004	0.0036	1.1	3.7	3.57	0.195	0.0068	4.73	0.53	0.198	55.65
105	DL9605-110	12.665	0.667	4.29	49.46	0.011	0.0099	1.01	3.69	0.313	3.56	0.0107	7.3	0.51	0.259	48.58

Appendix 3 Summary Table for the Hand Values and Total Hand Values of Objective and Subjective Results

		KES Hand Value					PhabrOmeter Value					Subjective Hand Value			
Sample	Article No.	Stiffness	Smoothness	Softness	SoftFeeling	THV	Group	Stiffness	Smoothness	Softness	Drape	Stiffness	Smoothness	Softness	THV
1	DL8065	1.93	4.13	4.43	3.32	1.93	Light	9.1948	10.1014	9.165	0.791	3.08	4.92	7.32	3.08
2	DL8085	2.86	3.59	3.39	2.64	1.89	Light	9.2273	9.7901	9.2199	0.703	3.44	5	7.2	3.2
3	DL8110	3.51	3.22	3.2	2.23	1.95	Light	8.6435	10.5899	7.9308	1.337	3.2	5	5.72	2.72
4	ZT-0426-65	3.31	3.24	2.95	2.66	1.82	S. Light	8.8981	10.1577	9.4464	0.924	3.8	4.8	6.2	2.92
5	ZT-0610-60	3.26	3.17	3.11	2.08	1.84	S. Light	9.1137	10.2133	9.3168	0.841	3.56	4.8	6.56	3
6	0426-60	3.72	2.35	1.53	1.19	1.21	S. Light	8.9444	10.2374	9.4293	0.92	3.2	5	6.64	3
7	0426-65	4.33	2.45	1.88	1.46	1.52	S. Light	8.8529	10.1397	9.5238	0.925	4.92	4.56	5.56	2.36
8	0426B-65	3.36	2.9	2.21	1.89	1.49	S. Light	8.9819	10.1146	9.4506	0.845	3.64	4.56	5.92	2.64
9	0610B-60	4.27	1.64	1.05	0.11	1.04	S. Light	9.0158	10.444	9.294	0.979	3	5.2	6.92	3.36
10	0610-65 (W)	2.51	5.99	6.21	5.63	3.08	S. Light	9.1437	10.1966	9.2339	0.84	3.64	4.64	6.8	2.72
11	0610-65	2.95	5.28	5.48	4.85	2.88	Light	9.1699	10.0449	9.2746	0.755	4.2	4.56	6.56	2.92
12	0610-70	3.04	3.44	3.7	2.04	2	Light	9.2203	9.8948	9.2083	0.724	3.2	4.8	6.64	3.08
13	0616-80	3.33	3.47	2.28	2.43	1.63	S. Light	8.9249	10.2051	9.4321	0.924	1.72	7.28	7.8	3.92
14	0616-110	3.79	3.89	2.88	2.73	2.08	Light	8.8377	8.8414	9.3952	0.995	2.8	6.92	7.44	3.8
15	0616-130	5.24	2.86	1.8	1.64	1.7	Light	9.299	8.8197	9.6919	0.78	4.28	6.72	5.8	3.2
16	0715-110	3.53	3.99	3.85	3.18	2.33	Light	8.6476	10.3113	8.0355	1.275	4.56	4.8	5.44	2.8
17	0716-100	4.93	1.81	1.2	0.41	1.25	Light	8.9914	9.3266	9.3275	0.784	4.36	5.64	5.64	2.92
18	0716-105	3.33	3.16	2.37	2.63	1.6	Light	8.732	8.9141	9.3718	1.024	2.64	6.36	7.2	3.44
19	0716-110	4.31	4.05	3.53	3.03	2.45	Light	8.8976	9.7905	8.8213	0.882	3.92	5.56	5.92	3.08
20	0716-110L	2.99	3.98	3.78	2.48	2.14	Light	8.5159	9.9416	8.3471	1.195	3.92	5.56	6.08	3.08
21	0716-120L	3.67	3.55	3.31	2.04	2.1	Light	8.6481	10.1287	8.3704	1.135	4	5.8	6.28	3.36
22	0718-100	6.08	1.7	0.51	0.44	0.99	Light	8.8824	10.3155	8.4612	1.026	3.28	6.72	6.72	3.56
23	0810-60	1.96	4.34	4.46	3.18	2.02	Light	9.1622	10.1726	9.1966	0.832	2.44	5.36	7.64	3.36
24	0913-120	5	3.65	3.98	2.84	2.58	Light	8.9601	8.8522	9.7344	0.912	4	4.2	5.44	2.44
25	3215-130	4.97	2.3	2.02	0.85	1.68	Light	9.2877	8.9958	9.3789	0.75	4.72	4.8	5.28	2.72
26	3216W-100	4.06	3.28	3.2	2.2	2.1	Light	8.8629	9.9546	8.6088	0.963	4.36	5.2	5.64	2.72
27	3226-115	4.79	2.95	2.45	1.76	1.92	Light	9.0281	9.6818	8.6146	0.927	4.72	5.36	5.56	2.64
28	3728-85	3.44	3.52	3.48	2.87	2.08	Light	8.6656	9.6907	8.7651	1.012	4.56	5	5.44	2.8
29	K055-55	2.24	5.15	5.15	5.08	2.53	Light	9.2144	10.0951	9.1558	0.786	3.08	5.44	7.08	3.36
30	NL0426-55	2.08	3.43	2.55	2.61	1.28	S. Light	9.0643	10.162	9.2779	0.865	2	6	7.92	3.44
31	K082-200	8.11	1.75	1.03	1.69	1.2	Light	9.6421	9.8594	9.2537	0.453	6.56	4.64	3.72	2.56
32	T112-180	8.38	2.26	3.81	1.63	2.28	Medium	8.2173	13.4621	5.6261	3.061	7.44	3	2.08	1.28
33	T112-210	9.82	1.69	4.54	1.15	2.09	Heavy	8.7782	12.2277	6.9019	2.107	7.72	3.44	2	1.44
34	T140-250	9.74	1.91	3.89	0.97	1.99	Heavy	9.5709	8.728	10.148	0.802	8.2	2.92	2	1.36
35	0426B-100G	4.23	3.04	2.05	1.89	1.67	Light	9.0311	8.8817	9.5104	0.88	3.92	5.72	6.56	3
36	0610-75G (G)	4.46	2.42	1.5	0.96	1.37	S. Light	9.0825	10.1715	9.3492	0.855	3.08	4.72	6.36	3.08
37	0610-75G	5.44	1.77	0.7	0.33	1.04	S. Light	8.9903	10.1095	9.4573	0.856	3.92	5.2	6	2.36
38	0716-110G	4.44	2.69	1.98	1.18	1.62	Light	8.8206	9.3963	9.1269	0.892	4.2	4.92	5.36	2.92
39	0012-120	5.17	4.07	4.7	2.59	2.86	Light	9.4401	8.6882	9.9064	0.785	4.92	4.44	4.64	2.56
40	0012-130	5.43	4.09	4.22	1.64	2.81	Light	9.5817	9.1986	9.6685	0.525	4.8	4	4.36	2.36
41	0516-145	6.05	4.36	4.76	2.94	3.04	Light	9.358	8.7726	9.784	0.78	5.44	4.28	4.2	2.44
42	0715-120BR	3.42	4.44	4.98	3.2	2.65	Light	8.8954	9.728	8.8123	0.894	3.72	4.44	4.72	2.64
43	3214-160	5.88	4.01	5.17	2.71	2.98	Medium	9.5625	9.435	9.471	0.47	5.2	5.36	4.56	2.56
44	3715-160	5.76	4.08	4.45	2.35	2.88	Light	9.5359	8.9476	9.7276	0.65	4.92	4.56	4.92	2.44
45	3912-130	4.75	4.05	4.66	2.7	2.78	Light	9.1366	9.0088	9.6188	0.777	4.56	4.2	5.36	2.36
46	3732-190	7.13	3.73	5.44	1.73	2.94	Medium	9.6398	10.1954	8.7829	0.663	6.36	3.8	4.36	2.36
47	3012-110	3.89	3.5	1.67	2	1.52	Light	9.1783	8.262	9.8378	1.069	2.36	7.8	7.72	4.08
48	0414-100	4.34	5.04	5.64	3.82	3.16	Light	9.1412	9.2615	9.5123	0.701	4.08	4.92	5.92	2.72
49	0414-160	6.76	3.82	5.27	2.41	2.96	Medium	10.1352	9.1962	9.9164	0.441	3.56	6.28	5.64	2.8
50	J0414-260	7.75	2.88	2.98	0.39	2.21	Medium	8.5914	10.4029	9.3056	1.048	5.56	6.72	4.72	3.2
51	Y0414-120	3.27	5.27	5.4	4.54	2.96	Light	8.92	9.3894	9.16	0.838	3.08	6.56	7.08	3.44
52	Y0414-160	5.04	4.97	5.16	4.07	3.21	Medium	9.4906	8.898	9.7878	0.678	4.64	6.2	4.92	3

53	Y0414-200 (G)	6.16	4.22	4.28	3.13	2.92		Medium	9.854	9.0937	9.7195	0.51		5.56	6.44	4.56	3
54	Y0414-200	7.39	3.85	3.91	2.1	2.72		Light	9.9141	8.9055	9.8609	0.598		5.56	6.72	5.08	3.08
55	3617-125 (P)	4.23	4.27	4.36	2.5	2.7		Light	9.4004	9.5665	9.4044	0.525		3.8	5.8	6	3.44
56	3617-125	4.05	3.71	3.81	1.92	2.37		Light	9.3727	9.5799	9.4149	0.528		3.56	5.8	6.44	3.56
57	3617-140	4.22	4.61	4.36	2.72	2.81		Light	9.4621	9.7731	9.262	0.489		3.8	5.28	6.2	3.36
58	00101-10824-120	1.54	5.13	4.12	4.46	2.06		Light	8.3828	9.5057	8.6803	1.198		2.2	6.8	8	4.2
59	0716-120L	2.92	4.31	4.27	3.59	2.33		Light	9.248	9.607	9.3	0.656		4.36	5	5.64	3
60	0716-110G	4.05	4.39	3.09	3.67	2.37		Light	9.134	9.859	9.354	0.722		3.64	5.56	6.2	3.56
61	3171-75	3.18	6.12	5.41	5.57	3.33		Light	8.826	9.914	9.698	0.865		4.28	5.08	6.44	3.08
62	3171-125	3.59	5.78	5.49	5.2	3.29		Light	8.163	10.026	10.01	1.257		5.2	3.92	4.2	2.36
63	3172-75	3.22	4.57	4.38	4.48	2.54		Light	8.962	9.918	9.532	0.803		4.56	4.36	6.2	3.08
64	3172-125	3.61	5.32	5.19	5.12	3.07		Light	8.76	9.789	9.675	0.89		4.92	4.36	4.92	2.56
65	3173-125	3.54	4.95	4.56	4.49	2.8		Light	8.825	9.777	9.654	0.858		3.92	4.44	5.92	2.8
66	4286-75	3.28	5.67	5.02	5.41	3.11		Light	8.934	9.924	9.534	0.817		3.64	4.36	6.08	3.2
67	3173-75	3.57	4.95	4.66	4.27	2.83		Light	8.868	9.947	9.646	0.85		3.36	5.36	6.72	3.36
68	3178-75	3.65	6	4.97	5.39	3.36		S. Light	9.671	10.154	10.843	0.567		3.56	5.2	6.28	3.08
69	3179-75	3.18	5.49	6.64	5.03	2.94		Light	8.797	10.014	9.694	0.899		3.56	4.8	6.08	3.08
70	3175-160	5.53	5.7	5.56	4.06	3.63		Medium	9.705	9.941	9.199	0.419		6.92	3.8	3.72	2.2
71	DL3173N-75	2.53	5.62	5.1	5.44	2.84		Light	9.013	9.867	9.397	0.785		3.08	4.92	6.72	3.44
72	DL3173N-125	2.6	6.23	5.84	5.62	3.22		Light	8.966	9.573	9.528	0.797		3.92	4.8	6	3.28
73	3171-125	3.78	5.15	5.14	4.27	3.03		Light	8.092	10.044	10.106	1.308		5.2	4.2	4.64	2.72
74	3172-125	3.71	5.21	5.22	4.76	3.05		Light	8.565	9.838	9.84	1.011		5.2	4.08	5	2.44
75	3173-125	3.65	5.69	5.83	5.08	3.29		Light	8.232	10.019	10.11	1.221		5.56	3.92	4.36	2.64
76	0610-65	2.04	5.6	5.02	4.69	2.63		Light	9.084	10.179	9.275	0.862		3.92	4.56	6.2	3.08
77	0716-120L	3.63	4.95	4.15	4.21	2.75		Light	9.152	9.463	9.475	0.718		5.28	4.64	4.64	2.72
78	0610-45	1.5	5.99	5.45	5.72	2.63		S. Light	9.381	9.676	11.317	0.839		3.36	4.64	6.64	3.36
79	0716-75L	1.52	5.94	5.23	6	2.59		Light	9.025	10.089	9.331	0.85		3.64	5.56	6.36	3.36
80	TX4292-85	2.89	5.99	4.95	5.36	3.13		Light	8.775	9.839	9.649	0.895		2.92	5.36	7.28	3.44
81	TX4293-80	3.26	4.72	4.02	4.51	2.53		Light	8.794	9.904	9.688	0.889		3.64	4.72	6.28	3.2
82	TX4294-75	3.88	4.92	4.02	4.09	2.78		Light	8.93	9.919	9.586	0.822		4	4.08	5.64	2.64
83	TX4295-80	3.43	5.23	4.3	4.9	2.84		Light	8.844	9.87	9.61	0.867		3.8	4.28	5.8	3.08
84	DL3171-75	3.03	4.24	4.13	3.6	2.32		Light	8.855	9.952	9.576	0.876		3.44	5.28	6.72	3.08
85	DL3171-125	3.52	6.16	5.53	5.46	3.46		Light	8.386	10.006	9.879	1.137		4.56	4	5.44	2.64
86	DL3172-75	2.38	5.71	5.13	5.75	2.83		Light	8.982	9.985	9.44	0.823		3.64	4.56	6.28	3.28
87	DL3173N-75	2.56	5.41	4.93	5.25	2.73		Light	8.985	9.949	9.461	0.817		3.28	4.92	6.56	3.2
88	DL3173N-125	3.71	5.91	5.31	5.33	3.37		Light	8.651	9.861	9.754	0.981		4	4.44	5.64	3.2
89	DL3173W-75	2.77	6	5.19	5.54	3.12		Light	8.948	9.997	9.469	0.844		3.28	4.8	6.64	3.2
90	DL3178-75	3.27	5.92	4.96	5.77	3.21		Light	8.814	10.042	9.573	0.917		4.28	4.8	6.08	3.08
91	DL3179-75	3.56	5.59	4.75	4.85	3.11		Light	8.893	10.026	9.579	0.881		4.2	4.44	6.28	3.2
92	2103C-130	5.56	4.05	2.82	2.48	2.43		Light	8.051	9.952	10.335	1.363		4.44	5.36	5.92	2.8
93	2105-65	1.63	5.22	4.67	5.14	2.24		S. Light	9.373	9.648	10.962	0.706		2.44	6.2	7.36	3.56
94	2604-130	4.97	6.49	5.9	4.7	3.98		Light	8.079	9.991	10.382	1.336		5.08	4.44	4.64	2.2
95	2806-110	3.11	5.83	5.86	5.9	3.2		Light	9.029	9.993	9.458	0.812		3.36	6.28	6.64	3.56
96	9303-035	3.39	6.85	7.98	6.22	3.68		Light	8.946	10.027	9.559	0.869		3.64	5.44	6.08	3.2
97	9315-50	2.03	5.33	3.6	4.9	2.23		S. Light	9.317	9.617	11.077	0.912		2.08	5.56	7.92	3.36
98	9509-45	1.13	6.21	5.5	5.88	2.57		S. Light	9.307	9.669	11.697	1.034		3.44	4.8	6.44	3.36
99	9604-70	2.24	6.2	5.08	6.22	3.01		S. Light	9.391	9.674	11.028	0.725		3.28	5.8	6.72	3.2
100	9605-75	1.21	5.75	4.88	5.87	2.32		Light	9.005	10.101	9.321	0.863		3.8	5.64	6.08	3.36
101	9710-75	1.22	6.07	5.16	6.1	2.51		Light	9.153	9.969	9.22	0.765		3.44	6.08	6.64	3.2
102	9901-80	2.18	7.58	6.99	7.04	3.85		Light	8.896	10.111	9.411	0.911		3.36	4.92	6.36	3.36
103	FL907-140	6.9	3.76	5.23	3.84	2.94		Medium	8.877	9.367	9.251	0.847		7.08	2.64	2.8	1.64
104	K055-45	1.08	7.26	6.59	7.43	3.17		S. Light	9.372	9.625	11.455	0.91		1.92	6	8.2	3.64
105	DL9605-110	2.43	5.25	4.95	4.75	2.62		Light	9.314	9.528	9.204	0.654		4.28	5.72	5.72	3.08

Appendix 4 Background Information of Judges in Subjective Measurement

Panel Size: 25					
Judges	Age	Gender	Education	Experience	Grade
1	33	M	PostDoc	over 15 yrs	Expert
2	38	F	PhD	over 15 yrs	Expert
3	30	F	PhD	over 10 yrs	Expert
4	30	M	PhD	over 10 yrs	Expert
5	28	F	PhD	over 10 yrs	Expert
6	28	M	PhD	over 8 yrs	Expert
7	27	F	Mphil	over 7 yrs	Expert
8	26	F	Mphil	over 6 yrs	Expert
9	27	F	Mphil	over 6 yrs	Expert
10	36	F	F.7	over 10 yrs	Expert
11	34	F	F.7	over 10 yrs	Expert
12	31	F	Degree	over 8 yrs	Expert
13	29	F	Aso. Deg.	over 8 yrs	Expert
14	26	M	Degree	over 5 yrs	Normal
15	28	F	Degree	over 5 yrs	Normal
16	22	M	Degree	over 3 yrs	Normal
17	22	F	Degree	over 3 yrs	Normal
18	21	F	Degree	over 3 yrs	Normal
19	21	F	Degree	over 2 yrs	Normal
20	21	F	Degree	over 2 yrs	Normal
21	35	M	PhD	None	Naïve
22	27	F	High Dip.	None	Naïve
23	27	M	F.5	None	Naïve
24	24	F	Degree	None	Naïve
25	23	M	Degree	None	Naïve

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